Fishery Data Series No. 22-13

Late-Run Kasilof River Chinook Salmon Sonar Assessment, 2019–2020

by

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August 2022

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General	
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics	
all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	′
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	″
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Adaptive resolution imaging sonar (ARIS) was used for the first time in 2018 to estimate the abundance of late-run Chinook salmon (*Oncorhynchus tshawytscha*) at river mile (RM) 8 of the Kasilof River. The same methods were used to estimate late-run Chinook salmon abundance in 2019 and 2020. In 2019, the sonar was operated from 15 June through 31 August. In 2020, the sonar was operated from 15 June through 22 August. Net upstream passage of late-run Chinook salmon greater than or equal to 75 cm mid eye to tail fork length (METF) as measured by ARIS was estimated to be 4,507 (SE = 184) in 2019 and 3,388 (SE = 165) in 2020. The 2019 cumulative late-run Chinook salmon abundance estimate of fish greater than or equal to 75 cm METF was higher than the 2018 and 2020 estimates. Run timing in 2019 and 2020 was earlier than in 2018.

Keywords: Chinook salmon, *Oncorhynchus tshawytscha*, abundance, adaptive resolution imaging sonar, ARIS, Kasilof River

INTRODUCTION

The Kasilof River is a turbid, glacially influenced stream in western Kenai Peninsula that originates at the outlet of Tustumena Lake and flows 19 river miles (RM) to the eastern shore of Cook Inlet (Figure 1). Two tributaries feed into the Kasilof River: Coal Creek at RM 4 and Crooked Creek at RM 7. The lower 5 RM of the Kasilof River is tidally influenced.

The Kasilof River supports populations of Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), pink salmon (*O. gorbuscha*), Dolly Varden (*Salvelinus malma*), and steelhead (*O. mykiss*; Johnson and Blossom 2017). Chinook salmon return to the Kasilof River in 2 runs: an early run that enters the river primarily in May–June and a late run that enters primarily in July–August. The early run is composed of naturally produced and hatchery-reared Chinook salmon destined for Crooked Creek. The naturally produced Crooked Creek stock is descended from both wild fish and naturalized hatchery fish (Waite 1983; Lipka et al. 2020). The hatchery-reared fish are the progeny of both wild and naturally produced Crooked Creek fish that were artificially spawned and reared in a hatchery before being released back into Crooked Creek as smolt. The late run is composed of a wild stock that spawns in the mainstem of the Kasilof River.

The early run of Kasilof River Chinook salmon supports an inriver sport fishery that occurs in May and June. The entire river is open to sport fishing for Chinook salmon during the early run, but most effort occurs below the Sterling Highway bridge crossing located at about RM 8 and primarily below the Crooked Creek confluence. The average annual sport harvest of early-run Chinook salmon (both naturally produced and hatchery-reared) between 2005 and 2016 was 1,464 fish (Begich et al. 2017). A personal use gillnet fishery occurs at the mouth of the Kasilof River in mid-June and harvests an average of 133 Chinook salmon annually (2005–2016, for both naturally produced and hatchery-reared; calculated from Lipka et al. 2020). Early-run Chinook salmon harvest in the commercial Eastside set gillnet (ESSN) fishery is unknown but considered negligible because the run timing of most of the early run precedes this fishery. Escapement of naturally produced and hatchery-reared Chinook salmon to the Crooked Creek weir (located 3.2 RM upstream from the confluence with Kasilof River) from 2005 to 2016 averaged 1,737 fish (Begich et al. 2017).

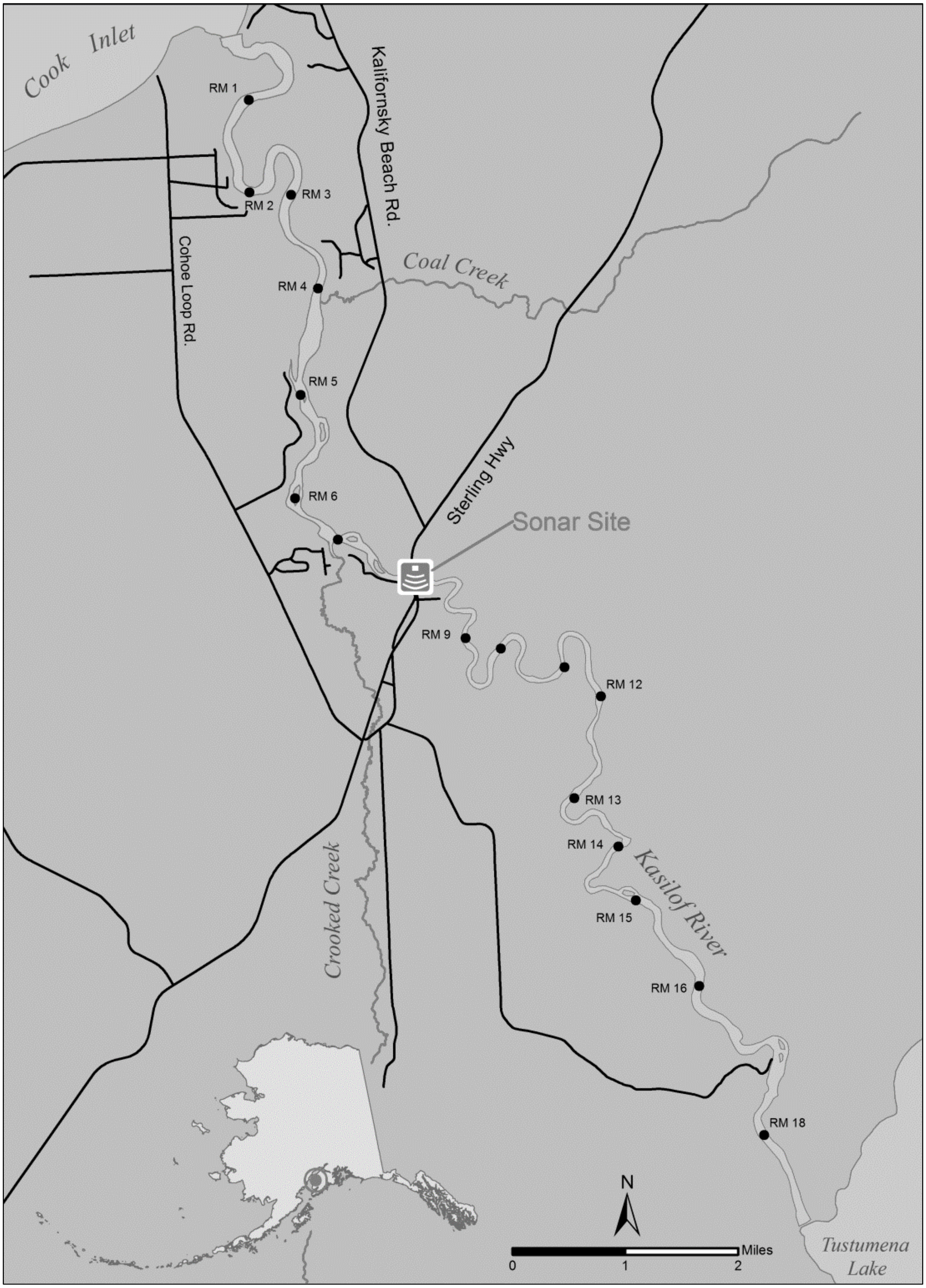

Figure 1.–Map of the Kasilof River showing the RM 8 sonar site, Kenai Peninsula, Southcentral Alaska.

A sport fishery also occurs for the late run of Kasilof River Chinook salmon, although effort and harvest are reduced relative to the early-run fishery. The late-run sport fishery (July 1–July 31) is prosecuted downstream of the Sterling Highway bridge. By regulation, sport fishing for Chinook salmon is prohibited upstream of the bridge during the late run. The average annual sport harvest of late-run Chinook salmon between 2013 and 2016 was 779 fish (calculated from Begich et al. 2017, page 107).[1] In addition, average annual harvest of late-run Kasilof River Chinook salmon in the ESSN fishery from 2013 to 2016 was 1,190 fish or about 25% of the total ESSN Chinook salmon harvest each year (calculated from Eskelin and Barclay 2018). Inriver abundance of late-run Chinook salmon is unknown for most years. Reimer and Fleischman (2012) conducted a mark–recapture study from 2005 to 2008 to estimate late-run Chinook salmon abundances. The mode of the mark–recapture inriver abundance estimates was 12,097 fish for 2005, 8,611 fish for 2006, 8,522 fish for 2007, and 8,276 fish for 2008.

The only salmon escapement monitoring project on the Kasilof River mainstem is a well-established sonar site located near RM 8 operated by the Alaska Department of Fish and Game (ADF&G), Division of Commercial Fisheries to estimate adult sockeye salmon escapement. From 2010 to 2017, this project operated 2 standard dual-frequency identification sonar (DIDSON) units (1 deployed near each river bank) to estimate salmon passage in conjunction with a fish wheel used to apportion estimates to species and collect age, sex, and length (ASL) data (Glick and Willette 2016b). Larger Chinook salmon are capable of swimming offshore of the fish wheel, so the fish wheel was used predominantly to apportion sockeye, pink, and coho salmon during the latter half of the sockeye salmon run when migrations of these smaller salmon species overlap.

To produce estimates of Chinook salmon escapement using sonar, accurate estimates of fish size at all ranges must be obtained. The standard DIDSON units used on the Kasilof River through 2017 did not provide the necessary resolution to accurately differentiate large Chinook salmon from other smaller species of salmon beyond approximately 10 m in range from the sonar (river width at the site is approximately 60 m). For this reason, the Kasilof River sockeye salmon sonar project was not capable of providing late-run Chinook salmon escapement estimates. In addition, the sockeye salmon sonar project only operated through the first or second week of August, whereas the 2005–2008 mark–recapture study showed that significant numbers of Chinook salmon continue to pass the site through the end of August.

The next generation of DIDSON technology, adaptive resolution imaging sonar (ARIS), provides higher resolution images that allow accurate fish length measurements out to 30+ m, thus providing the ability to estimate fish size across the entire river at the Kasilof sonar site. This technology has been used by ADF&G on the Kenai River to estimate large (≥75 cm mid eye to tail fork [METF]) Chinook salmon passage since 2013 (Miller et al. 2016a, 2016b; Key et al. 2017, 2019). In 2018, for consistent methodology, the 2 DIDSON units used on the Kasilof River were replaced with 2 ARIS units like those used on the Kenai River to estimate the abundance of Chinook salmon 75 cm METF or longer.

There are advantages to using the same length threshold for both the Kasilof and Kenai Rivers. First, threshold estimates can be combined with estimates from other projects, such as those from the ESSN Chinook salmon harvest genetic stock information project (Eskelin and Barclay 2017), to estimate the annual total run size of large Kasilof River late-run Chinook salmon. Second, the

[1] The 2016 harvest estimate was obtained from Jenny Gates, Sport Fish Biologist, ADF&G, Soldotna, personal communication.

same ADF&G personnel are responsible for processing both Kenai and Kasilof River sonar data. These personnel are trained to visually identify ARIS fish images near and above the 75 cm threshold for measurement (Key et al. 2017), so using the same threshold for both rivers allows streamlined data processing without developing additional methods for data collected by the ARIS located at the Kasilof River.

A 75 cm METF threshold effectively separates Chinook salmon from other species on the Kasilof River. Length information from Kasilof River Chinook, coho, and sockeye salmon migrating during August[2] was compiled from a variety of sources (Figure 2) to examine the utility of a 75 cm threshold for Kasilof River salmon. Almost all sampled sockeye and coho salmon were less than the 75 cm threshold, although a small percentage of coho salmon (about 1.5%) could exceed the threshold after accounting for the error associated with measuring fish length using imaging sonar. The most recent Kasilof River coho salmon abundance estimate in August 2008 was approximately 6,700 fish (derived from Bromaghin et al. 2010). If 1.5% of those fish were measured as 75 cm or longer, approximately 100 coho salmon would have been included in a sonar count of large Chinook salmon.

Historically, most of the inriver run of Kasilof River Chinook salmon near the sonar site is larger than a 75 cm METF threshold and therefore would be counted by sonar, although missed Chinook salmon would be predominantly ocean-age-2 males. This is based on the 2005–2008 mark–recapture study of Kasilof River Chinook salmon (Reimer and Fleischman 2012) where approximately 91% of ocean-age-2, 6% of ocean-age-3, and 0% of ocean-age-4 or -5 fish were less than 75 cm METF. Additionally, 84% of captured ocean-age-2 fish were male.

Net upstream passage of Chinook salmon greater than or equal to 75 cm METF into the Kasilof River in 2018 was estimated to be 3,458 (SE = 166; Miller et al. 2020). The same methodologies used in 2018 were used to estimate net upstream passage of large (≥75 cm METF) Chinook salmon in 2019 and 2020.

OBJECTIVE

The objective of this project was to estimate the daily net upstream passage of salmon 75 cm METF or longer past RM 8 of the Kasilof River from 15 June through 31 August such that the seasonal estimate is within 10% of the true value 95% of the time.

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2 Available coho and Chinook salmon length data came from projects that sample multiple spawning stocks. Samples collected in August are probably most representative of those that will pass the sonar site during the sonar project dates.

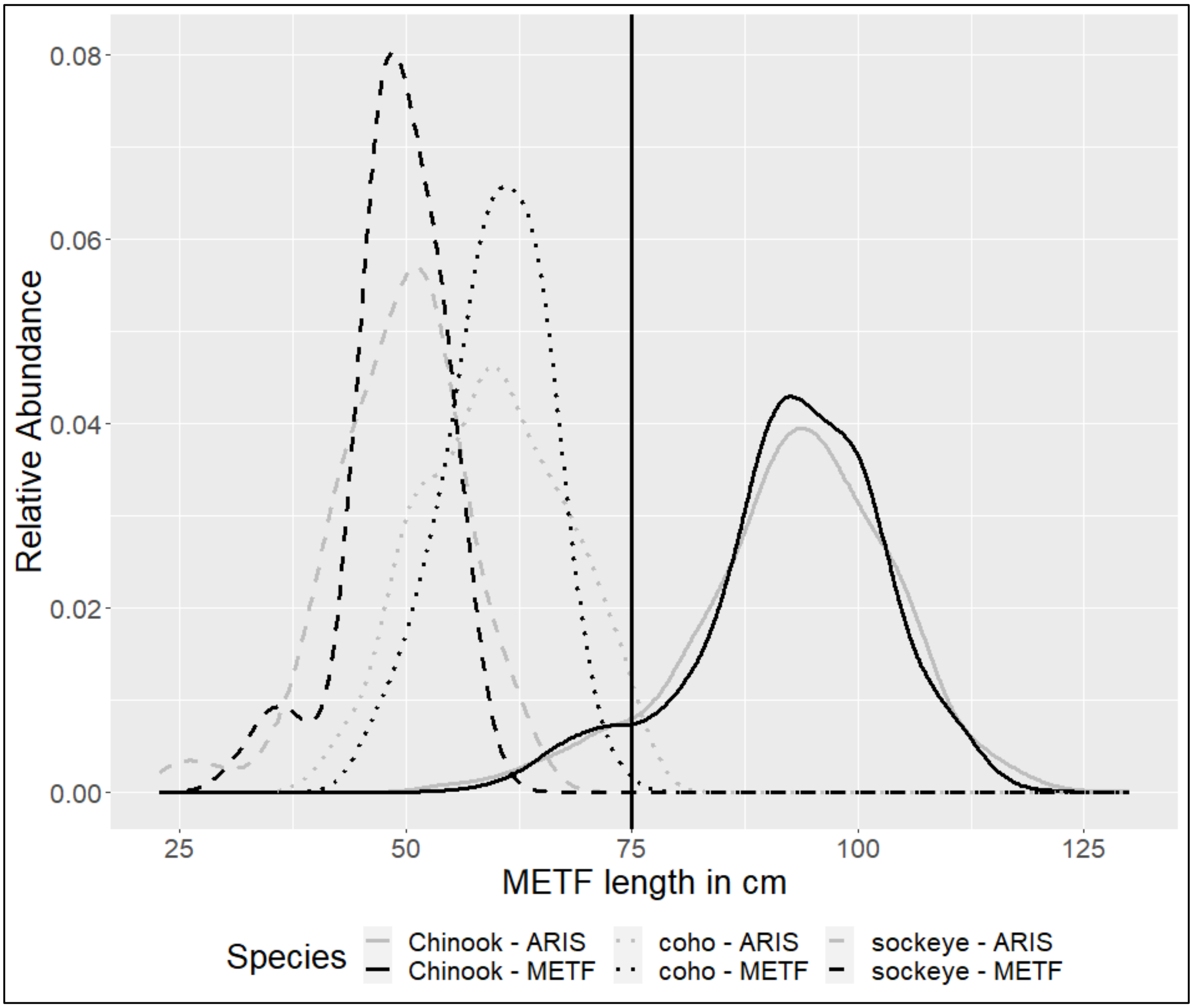

Figure 2.–Length distributions of coho, sockeye, and Chinook salmon in the Kasilof River.

Source: Reimer and Fleischman (2012) used 5.0-inch and 7.5-inch mesh gillnets in 2005–2008 to capture Chinook salmon during August in an area downstream of the sonar site. Gates et al. (2009, 2010) used 4.5-inch mesh gillnets in 2007 and 2008 to capture and tag adult coho salmon in the latter half of August in an area upstream of the sonar site. Sockeye salmon length data are from the Kasilof River fish wheel in August 2017 (Wendy Gist, personal communication, ADF&G Fisheries Biologist, Soldotna, Alaska).

Note: Dashed lines illustrate the derived length distribution of each species after accounting for ARIS length measurement error (Normal[0, 4.9 cm] estimated from tethered fish studies conducted on the Kenai River (*cf*. Miller et al. [2016]). "ARIS" means ARIS length, "METF" means mid eye to tail fork length.

METHODS

ADF&G Division of Commercial Fisheries (CF) and Division of Sport Fish (SF) worked cooperatively at the same site and used the same equipment to enumerate fish in the Kasilof River. CF was responsible for enumerating sockeye salmon as described in Glick and Faulkner (2019), whereas SF was responsible for enumeration of large Chinook salmon as described below.

SITE DESCRIPTION

The CF sonar site is located near RM 8 just upstream of the Sterling Highway bridge (Figure 1). River width at this location increases throughout the summer as discharge increases, reaching a maximum width of approximately 60 m in August. The substrate slopes gradually from each bank (with a slightly steeper incline in the first 3 m of the north bank) and is composed mostly of large rocks 20–60 mm in diameter with larger rocks and boulders exceeding 1 m^3 along the north bank (Glick and Willette 2016b).

ACOUSTIC SAMPLING

Acoustic sampling occurred from 15 June to 31 August in 2019 and from 15 June to 22 August[3] in 2020. Although few late-run Chinook salmon pass the RM 8 sonar site in June, monitoring of late-run Chinook salmon began the same date (15 June) that monitoring began for sockeye salmon. Late-run Chinook salmon passage estimates could be inflated if early-run Chinook salmon destined for Crooked Creek in late June strayed upriver past the RM 8 site prior to returning downriver to enter Crooked Creek. Early-run fish that may have temporarily strayed upriver past the sonar site were accounted for in the late-run Chinook salmon estimate by subtracting downstream passing fish from the upstream count (see below).

Acoustic sampling operations were consistent with those described in Glick and Willette (2019). One ARIS 1800 system was deployed from each bank. The ARIS systems were each configured with a standard lens and operated at a frequency of 1.8 MHz (nearshore) and 1.1 MHz (offshore) and set to ninety-six 0.3° × 14° beams to provide the resolution necessary for obtaining accurate length measurements at all ranges. Profiles of the river bottom were created following the methods of Maxwell and Smith (2007) at the start of the season and again when the river had risen to determine the best beam fit and aim for the transducer. The best beam fit included full coverage of the water column at close range where most sockeye salmon migrate. A narrow vertical beam width in this region would compromise detection of sockeye salmon. Early in the season, when water levels were low, 8° concentrator lenses were used as necessary to adjust the vertical beam width to better fit in the water column and thus decrease vertical interference from surface and bottom reverberation. Later, as water levels rose, the concentrator lenses were removed to allow for better coverage of the water column. The concentrator lenses did not affect horizontal beam width. Components of the ARIS 1800 system are listed in Table 1. Key et al. (2017) provide further detail on the ARIS system and a comparison with DIDSON.

Table 1.–ARIS system components used for data collection.

System component	Quantity	Description
Sonar	2	ARIS 1800 (north bank and south bank)
Lens assembly	2	standard lens for ARIS 1800 model with ~14° × 28° beam pattern
Concentrator lens	2	8° concentrator lens (1 for each sonar) used 15–29 June on north bank and 15 June–12 July on south bank
Remote pan and tilt	2	Sound Metrics AR2 rotators—controlled via ARIScope software
Data collection computer	2	Dell Precision 7520 laptop computers (1 for each sonar)

3 Sampling was terminated prior to 31 August due to budget constraints, but as it turns out, 22 August was also the third consecutive day of counts less than 1% of total counts to date, a passage rate at which other escapement enumeration projects normally terminate operations due to low fish passage (Glick and Willette 2018).

Sampling was controlled by computers housed in a "sonar shack" located on the south bank. Communication cables from the south-bank ARIS unit fed directly into the south-bank ARIS Command Module and data collection computer (Figure 3). On the north bank, data from the ARIS system was transmitted via a wireless bridge to a data collection computer on the south bank (Figure 3). A battery bank, charged daily using a combination of solar panels and a generator, provided power to the north-bank sonar electronics and wireless bridge. AC power was used to power all south-bank equipment. The ARIS units were mounted on Sound Metrics Corporation (SMC) AR2 pan-and-tilt units for remote aiming in the horizontal and vertical axes. The sonar and rotator units were deployed in the river using an aluminium H-style mount (Figure 4). As described in Glick and Willette (2019), deflection weirs were installed on each bank to force fish to pass offshore of the sonar and through the insonified zone. In the horizontal plane, the sonars were aimed perpendicular to the flow of the river current to maximize the probability of insonifying migrating salmon from a lateral aspect. In the vertical plane, the sonars were aimed to insonify the near-bottom region of the river. Internal sensors in the ARIS units provided measurements of compass heading, pitch, and roll as well as water temperature.

In designing ARIS, the manufacturer (SMC) separated the data collection (ARIScope) and data processing (ARISFish) software components. In addition to transmit frequency mentioned above, ARIScope has several data collection parameters that are user selectable including frame rate, window length, sample period, transmit pulse width, focus, transmit power level, and receiver gain. The maximum achievable frame rate was used for each stratum. Frame rate for each stratum was arrived at empirically by first fixing the parameters for start and end ranges and sample period for each stratum and then finding the maximum achievable frame rate. Window length varied depending on the range (in meters) of the stratum being sampled; in this case, there were 2 strata (nearshore [approximately 1–10 m] and offshore [approximately 10–30 m]) per ARIS system (south bank or north bank). In combination with transmit pulse width, sample period (or equivalently, the detail parameter) controls the downrange resolution for the image. Most data were collected at a sample period of 10 µs (microseconds; approximately 1,250 samples/beam for the 1–10 m stratum and 2,600 samples/beam for the 10–30 m stratum). The 10 µs resolution has been recommended by the manufacturer (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA) for the Kenai River, and tethered fish experiments conducted by Miller et al. (2016a) in the Kenai River found that the resolution settings tested for data collection (5 µs, 10 µs, and 27 µs) had minimal effect on the accuracy of ARIS length (AL) measurements and that a sample period of 10 µs provided an adequate balance between the accuracy of AL measurements and the amount of storage space required for processing and archiving data in the office. Transmit pulse width varied by stratum. As the insonified range increases, longer transmit pulse widths are generally required for sufficient power to achieve the greater range. At ranges beyond 10 m, the transmit pulse width was set to "Auto" or was manually set to ensure the transmit pulse width was long enough to get 2 samples within the transmit pulse as recommended by the manufacturer (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA). At ranges less than 10 m, transmit pulse width was set long enough to get 1 sample within the transmit pulse (sample period plus 2 microseconds, also recommended by the manufacturer). Transmit level (transmit power) was set to maximum for each stratum but receiver gain varied by stratum up to the maximum setting of 24 dB. In low scatter environments at close range, high receiver gain settings can amplify problems caused by ringing. In the nearshore stratum (for both south bank and north bank), the setting was reduced from maximum based on image quality. In the offshore stratum (for both south bank and north bank), where the signal is more diminished and lower gains can cause detection issues, gain settings were set to 24 dB. Finally, the autofocus feature was enabled for all data collection so that the sonar automatically set the lens focus to the midrange of the selected range window.

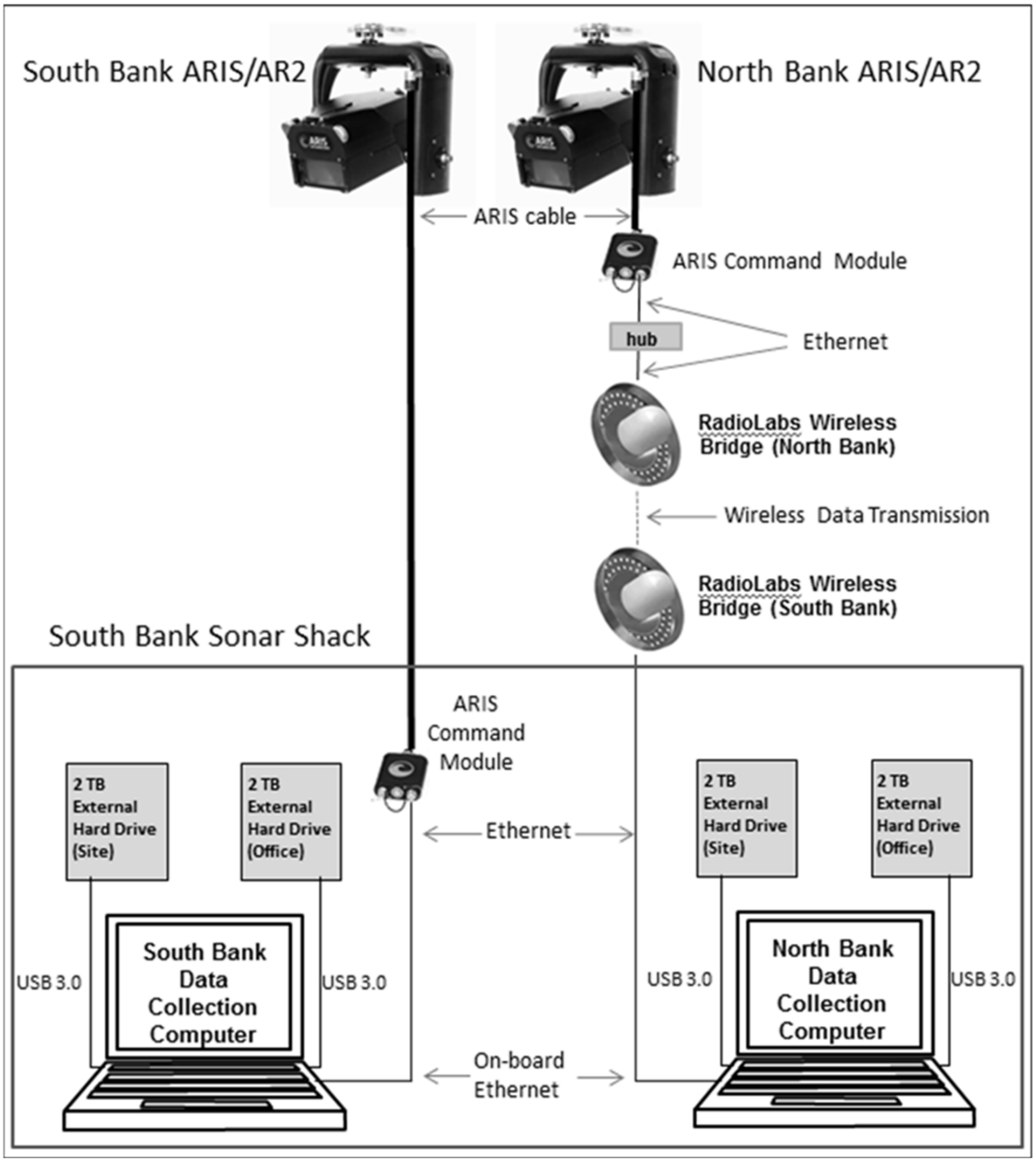

Figure 3.–ARIS data collection schematic for the Kasilof River.

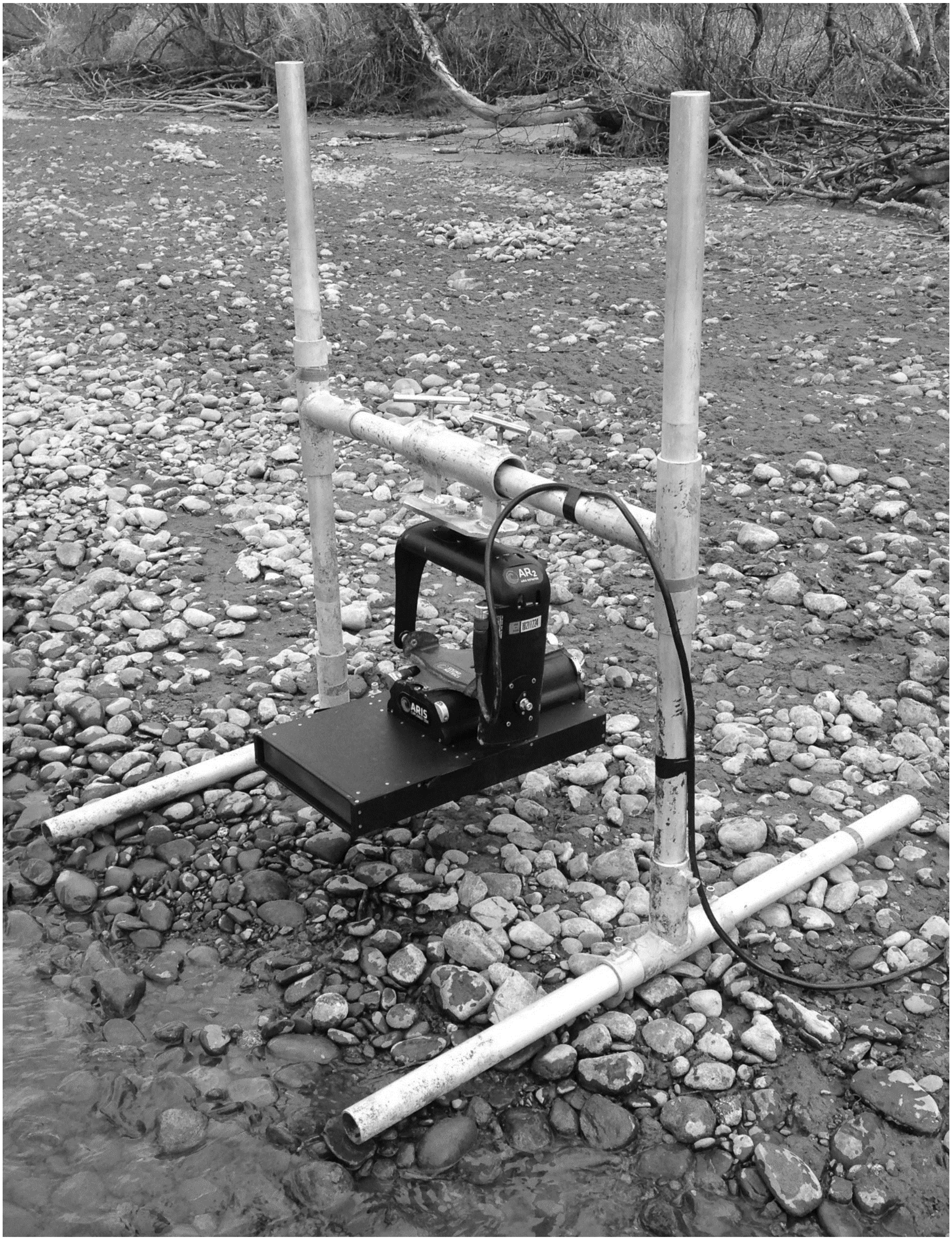

Figure 4.–ARIS mounted on an aluminum H-mount for nearshore deployment.

A systematic sample design (Cochran 1977) was used to sequentially sample discrete range strata ("range windows") for a total of 10 minutes per hour for each stratum. The ARIS was programmed to automatically sample each range stratum using ARIScope. Dividing the total insonified range into shorter range strata allowed the aim of the sonar beam to be optimized for sampling the given river section (i.e., generally the aim must be raised in the vertical dimension as sections farther from shore are sampled), and the reduced window size made it easier to count fish throughout the range at high passage rates. Using multiple range strata also allowed for data at different ranges to be collected at different frequencies to optimize image resolution. The ARIS on each bank was programmed to sample 2 range strata (approximately 1–10 m and 10–30 m) and was operated 24 hours per day, 7 days per week. Data collection parameters were adjusted throughout each season as water levels rose and as aims were refined (Tables 2–5).

Table 2.–Summary of sonar stratum range changes by date at the Kasilof River sonar site, 2019.

			Coverage range (m) by date		
Sonar location	Range stratum	Time (min)[a]	15 June	4 July[b]	22 July[c]
North bank	1	:10	0.7–9.6	0.7–9.6	0.7–9.6
	2	:00	9.6–26.6	9.6–30.0	9.6–31.5
South bank	1	:10	0.7–9.6	0.7–9.6	0.7–9.6
	2	:00	9.6–26.6	9.6–30.0	9.6–30.0

[a] Sample start time in number of minutes past the top of the hour.

[b] The sonars on both banks were moved closer to shore due to rising water level. The stratum 2 range was extended to 30 m on both banks.

[c] The south bank sonar moved 1.5 m closer to shore on 18 July due to rising water level. As a result, the stratum 2 range was extended to 31.5 m on 22 July.

Table 3.–Summary of sonar stratum range changes by date at the Kasilof River sonar site, 2020.

			Coverage range (m) by date		
Sonar location	Range stratum	Time (min)[a]	15 June	2 July[b]	23 July[c]
North bank	1	:10	0.7–10.0	0.7–10.0	0.7–10.0
	2	:00	10.0–26.0	10.0–29.0	10.0–30.0
South bank	1	:10	0.7–10.0	0.7–10.0	0.7–10.0
	2	:00	10.0–26.0	10.0–29.0	10.0–30.0

[a] Sample start time in number of minutes past the top of the hour.

[b] The sonars on both banks were moved closer to shore due to rising water level. The stratum 2 range was extended to 29 m on both banks.

[c] The sonars on both banks were moved closer to shore due to rising water level. The stratum 2 range was extended to 30.0 m on both banks.

Table 4.–Example of sampling schedule and ARIScope parameter values from 15 July 2019, Kasilof River sonar.

Sonar location	ARIS serial no.	Range stratum	Time (min)[a]	Frame rate (fps)[b]	Start range (m)	End range (m)	Frequency (MHz)	Transmit level	Gain (dB)	Pulse width (µs)	Start delay (µs)	Sample period (µs)	Samples per beam	Pitch (°)	Heading (°)
North bank	1692	1	:10	11.6	0.7	9.6	High (1.8)	Max	20	12	958	10	1,218	−5.3	162
		2	:00	3.8	9.6	30.0	Low (1.1)	Max	24	20	13,145	10	2,794	−5.3	161
South bank	1712	1	:10	11.6	0.7	6.6	High (1.8)	Max	20	12	957	10	1,218	−2.5	316
		2	:00	3.8	9.6	30.0	Low (1.1)	Max	24	20	13,136	10	2,788	−2.5	318

[a] Sample start time in number of minutes past the top of the hour.
[b] Frame rate in frames per second.

Table 5.–Example of sampling schedule and ARIScope parameter values from 15 July 2020, Kasilof River sonar.

Sonar location	ARIS serial no.	Range stratum	Time (min)[a]	Frame rate (fps)[b]	Start range (m)	End range (m)	Frequency (MHz)	Transmit level	Gain (dB)	Pulse width (µs)	Start delay (µs)	Sample period (µs)	Samples per beam	Pitch (°)	Heading (°)
North bank	1692	1	:10	11.2	0.7	10.0	High (1.8)	Max	20	12	949	10	1,262	−4.6	160
		2	:00	4.0	10.0	29.0	Low (1.1)	Max	24	20	13,582	10	2,580	−4.6	159
South bank	1712	1	:10	11.2	0.7	10.0	High (1.8)	Max	15	12	949	10	1,262	−3.5	324
		2	:00	4.0	10.0	29.0	Low (1.1)	Max	24	20	13,571	10	2,579	−3.6	325

[a] Sample start time in number of minutes past the top of the hour.
[b] Frame rate in frames per second.

ARIS video files were stored onto 2 sets of 2 TB external hard drives (Figure 3). One set was kept at the sonar site where CF staff manually counted all fish images from a computer screen in either video playback mode or echogram mode to estimate the numbers of sockeye salmon passing the sonar using methods described in Glick and Willette (2019). The other set of hard drives was transported daily by CF or SF staff to the Soldotna ADF&G office where SF staff conducted manual measurements of fish images as described in the following section using copies of the same 10-minute data files that were used to produce sockeye salmon escapement estimates. A copy of an Excel spreadsheet containing preliminary hourly fish counts by stratum for the day (produced daily by CF field staff) was included on data drives transported to the office.

MANUAL ARIS FISH LENGTH MEASUREMENTS

Measurements of fish length were obtained using ARISFish V2.7 software supplied by SMC. Detailed instructions for taking manual measurements and the software settings and parameters that were used for this project are given in Appendix A1. Electronic echograms provided a system to manually count, track, and size individual fish (Figure 5).

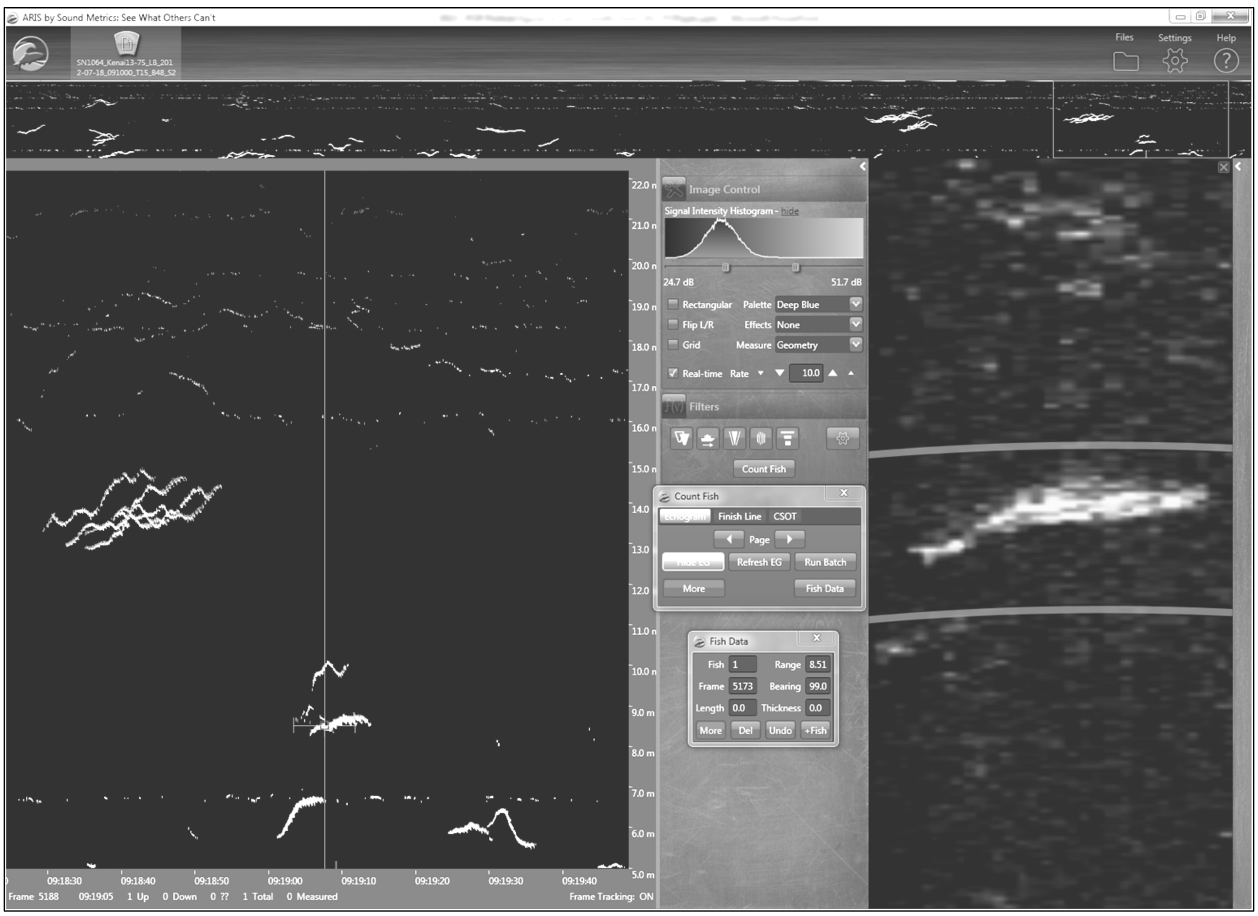

Figure 5.–ARISFish display window showing an echogram (left) with traces of migrating fish that can be simultaneously displayed in video mode (right) where fish images can be enlarged and measured.

To avoid the problem of counting fish in multiple spatial strata, which would have created a positive bias in the passage estimates (Appendix A2), measured fish were subjected to a “centerline rule” (Appendix A3). Only those fish that cross the longitudinal central axis of the ARIS video image were considered candidates for measuring. Fish that did not cross the centerline were ignored.

For this study, fish size was divided into 2 categories based on ARIS length (AL) measurements. Fish with AL measurements greater than or equal to 30 cm and less than 75 cm are referred to as "small fish." The minimum length criterion of 30 cm was chosen to encompass almost all sockeye salmon passing the sonar site based on length measurements collected from the fish wheel (Figure 2). Fish with AL measurements greater than or equal to 75 cm are referred to as "large fish." Based on tethered fish experiments conducted in the Kenai River and length relationships of free-swimming fish in the Kenai River, Miller et al. (2016a) concluded that a fish measuring 75 cm AL is also approximately 75 cm METF.

Estimates of large-fish abundance were produced by this project. Throughout the season, all large fish were counted and measured, and travel direction (upstream or downstream) was automatically recorded. In the offshore strata, where fish passage rates were relatively low, length and direction of travel were recorded for all salmon-shaped fish regardless of size. In the nearshore strata, where fish passage was relatively high due to large numbers of sockeye salmon, 2 sampling protocols were used depending on hourly nearshore stratum counts (10-minute samples) provided by CF:

- If the hourly 10-minute count in the nearshore stratum was less than 50 fish, length and direction of travel were recorded for all salmon-shaped fish greater than or equal to 30 cm AL that met the centerline rule (Appendix A3) for that stratum.
- If the hourly 10-minute count in the nearshore stratum exceeded 50 fish, the lengths of the first 5 fish in each sample period were measured and recorded regardless of size. The 5-fish protocol is not required for the Kasilof River but mimics that used on the Kenai River to allow consistency for technicians that were measuring samples from both rivers. For the remainder of the sample (after the first 5 fish), only fish in video images that visually appeared[4] to be near 75 cm AL were measured, and only those fish that measured greater than or equal to 75 cm AL were recorded. Fish less than 75 cm AL were not recorded in any way, including fish chosen for measurement that turned out to be less than 75 cm. For the remainder of this report, we will refer to this measurement protocol as the "large fish only" (LFO) protocol.

Abundance could be underestimated if fish were missed using LFO processing. To assess this bias in 2018, Miller et al. (2020) did postseason reprocessing of all files that were selected for LFO processing inseason. They measured all fish in each file and found that approximately 91% of the fish present were counted using the inseason LFO procedure. This percentage was based on a small sample (23 fish). To verify the Miller et al. (2020) results from the 2018 season, all files that were selected for LFO processing during the 2019 season were also reprocessed postseason, measuring all fish in the file.

DATA ANALYSIS

Fish Passage

Each ARIS system was scheduled to operate 10 minutes per hour for each spatial stratum, 24 hours per day. There were 2 spatial strata (approximately 1–10 m and 10–30 m) sampled per ARIS system (south or north bank). The number of fish y that satisfied a set of criteria X (e.g., fish with

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[4] Technicians rely on professional judgement to determine if fish are close to 75 cm AL. Accurate judgement is honed early in the season when low passage rates result in every fish being measured.

ARIS length equal to or greater than 75 cm and that migrated in an upstream direction) during day *i* were estimated as follows:

$$\hat{y}_i = \sum_k \sum_s \hat{y}_{iks} \tag{1}$$

where $\hat{y}_{iks}$ is fish passage in stratum *s* of transducer *k* during day *i*, which was estimated as

$$\hat{y}_{iks} = \frac{24}{h_{iks}} \sum_{j=1}^{h_{iks}} \hat{y}_{ijks} \tag{2}$$

where h_{iks} is the number of hours during which fish passage was estimated on day *i*, and $\hat{y}_{ijks}$ is hourly fish passage during hour *j*, which was estimated as

$$\hat{y}_{ijks} = \frac{60}{m_{ijks}} c_{ijks} \tag{3}$$

where

m_{ijks} = number of minutes (usually 10) sampled, and

c_{ijks} = number of fish satisfying criteria X (e.g., upstream direction of travel; ARIS length greater than or equal to 75 cm).

Due to systematic sampling in time, the variance of the daily estimates of *y* was approximated using a successive difference model[5] (Wolter 1985) with adjustments for missing data as follows:

$$\hat{V}[\hat{y}_i] \cong 24^2(1-f)\frac{\sum_{j=2}^{24} \phi_{ij}\phi_{i(j-1)}\left(\hat{y}_{ij} - \hat{y}_{i(j-1)}\right)^2}{2\sum_{j=1}^{24}\phi_{ij} \sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}} \tag{4}$$

where *f* is the sampling fraction (temporal sampling fraction, usually 0.17), ϕ_{ij} is 1 if $\hat{y}_{ij}$ existed for hour *j* of day *i*, or 0 if not, and

$$\hat{y}_{ij} = \sum_k \sum_s \hat{y}_{ijks} \tag{5}$$

Downstream estimates of passage were obtained by changing criteria X for fish counts c_{ijks} in Equation 3 to downstream fish greater than or equal to 75 cm AL. Estimates of daily net upstream passage were obtained by calculating separate estimates of upstream and downstream passage (Equations 1–3) and subtracting the downstream estimate from the upstream estimate. The

[5] This is an assessment of the uncertainty due to subsampling (counting fish for 10 minutes per hour and expanding). The formulation in Equation 4 may be conservative in the sense that it has been shown to overestimate the true uncertainty when applied to sockeye salmon passage data (Reynolds et al. 2007; Xie and Martens 2014). We considered the variance estimator recommended by Reynolds et al. (2007) but found the estimated variance to be functionally interchangeable.

estimated variance of net upstream daily passage is the sum of the upstream and downstream variances.[6]

LFO Protocol Analysis

To evaluate bias associated with large fish only (LFO) processing, all strata counted using LFO processing in season for both 2018 and 2019[7] were recounted by the project biologist after each season using the standard procedure of measuring every fish. Herein, we use Bayesian methods to update the analysis done in 2018 (Miller et al. 2020) so that estimates from this report reflect all of the data we have collected on LFO processing error. Updating the 2018 estimates makes sense because both the 2018 and 2019 datasets were collected with identical methods, although the 2019 dataset is roughly 5 times as large as the 2018 dataset.

Postseason counts were conducted with additional scrutiny and were intended to verify LFO counts. Because we were interested in fish missed during LFO processing, we removed fish from the LFO count if they were later determined to be less than 75 cm in length.

The number of large fish counted during hourly counts using LFO processing in year t, x_t, was binomially distributed with parameters N_t, the number of large fish counted when all fish were measured, and θ, the proportion of N_t, actually counted during LFO processing:

$$x_t \sim \text{Binom}(\theta, N_t) \tag{6}$$

Our parameter of interest, θ, is the estimated mean bias resulting from missed large fish during LFO sampling. We overestimate bias associated with LFO processing because while a large fish not included in the LFO count could have been missed while scanning for large fish (an LFO processing error), it could also have been seen and incorrectly measured smaller than 75 cm (a measurement error). In the latter case, measurement errors can occur in both directions and are assumed to not introduce bias.

Parameters were estimated using a Bayesian statistical model for binomial data with annual updating. For 2018 data, a noninformative beta(0, 0) prior distribution was used (Miller et al. 2020), whereas for 2019 data, the 2018 posterior, beta(21, 2), was used.

RESULTS

Data collection occurred from 15 June through 31 August in 2019 and from 15 June through 22 August in 2020. A total of 69,739 fish images 30 cm (ARIS length; AL) or larger were measured in 2019 of which 981 were 75 cm AL or larger. A total of 79,901 fish images 30 cm AL or larger were measured in 2020 of which 756 were 75 cm AL or larger. Small fish dominated passage during both years.

SIZE DISTRIBUTION

Mean length of "small fish" (30 cm ≤ AL < 75 cm) was 51.4 cm in 2019 and 50.5 cm in 2020. Mean length of "large fish" (≥75 cm AL) was 90.7 cm in 2019 and 92.9 cm in 2020 (Figures 6 and 7).

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[6] This calculation assumes independence between the daily abundance estimates. We considered a sampling design that does not require an independence assumption (Reynolds et al. 2007) but found the estimated seasonal variance to be functionally interchangeable.

[7] Results and conclusions drawn from the analyses conducted in 2018 and 2019 precluded the need to repeat the analysis again in 2020.

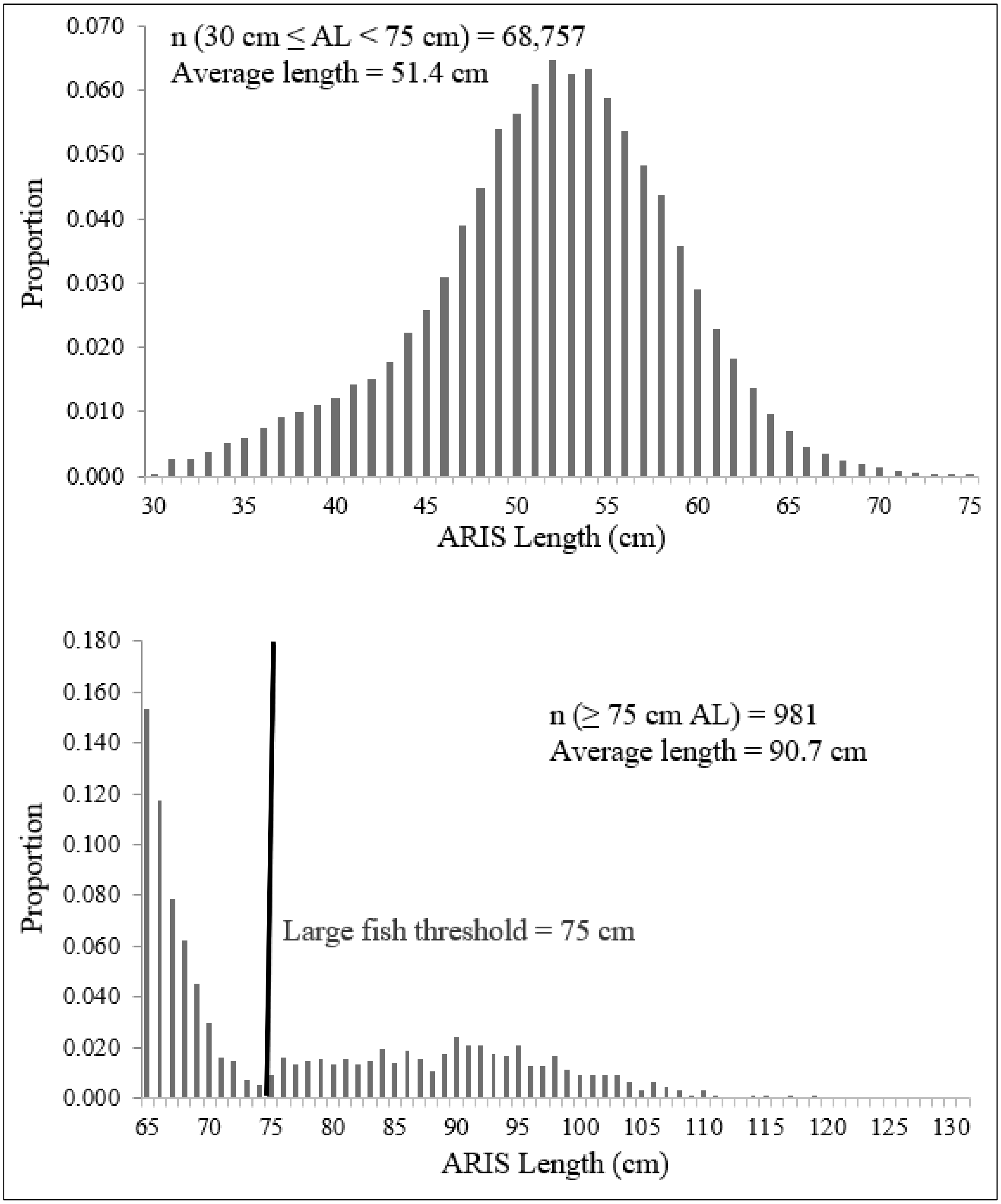

Figure 6.–Length frequency distribution of small fish (30 cm ≤ AL < 75 cm; top) and large fish (≥75 cm AL; bottom), Kasilof River sonar project, 2019.

Note: Although the large fish threshold is 75 cm AL, the bottom graph plots the length frequency distribution of all fish greater than or equal to 65 cm AL to show the distribution on both sides of the 75 cm AL threshold.

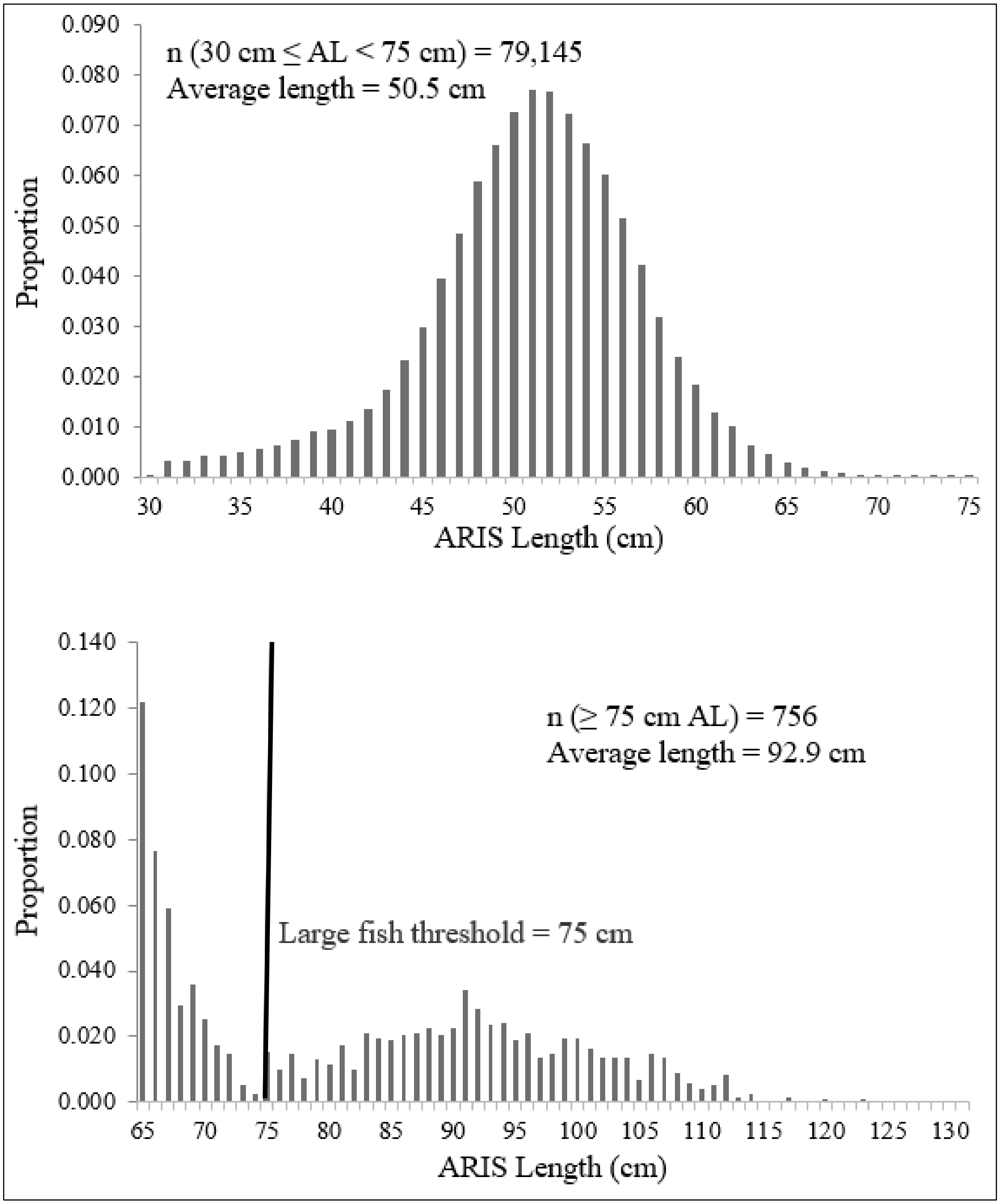

Figure 7.–Length frequency distribution of small fish (30 cm ≤ AL < 75 cm; top) and large fish (≥ 75 cm AL; bottom), Kasilof River sonar project, 2020.

Note: Although the large fish threshold is 75 cm AL, the bottom graph plots the length frequency distribution of all fish greater than or equal to 65 cm AL to show the distribution on both sides of the 75 cm AL threshold.

SPATIAL AND TEMPORAL DISTRIBUTION

The majority of upstream migration past the sonar (summed over offshore and inshore) during 2019 and 2020 occurred on the north bank of the river (68% of small fish and 66% of large fish in 2019 [Figure 8]; 60% of small fish and 74% of large fish in 2020 [Figure 9]). Over 45% of the upstream passage of large fish occurred in the north bank inshore stratum alone during both years. In 2019, the majority of downstream passage (both small and large fish) occurred on the south bank with 90% of all small fish downstream passage occurring in the south bank inshore stratum (Figure 8). In 2020, most of the downstream passage of small fish occurred in the south bank stratum whereas the majority of downstream passage of large fish occurred in the north bank stratum (Figure 9). Daily percentages of large fish that were bound upstream and downstream are tabulated in Appendices B1 and B2.

Small fish migrated closer to the riverbank than large fish, although small fish were still detected midriver (Figures 10 and 11). Median distance of passage from the face of the transducer for small fish in 2019 was 3.3 m on the north bank and 3.7 m on the south bank (Figure 10). Median distance of passage for large fish in 2019 was 5.6 m on the north bank and 7.5 m on the south bank (Figure 10). Median distance of passage from the face of the transducer for small fish in 2020 was 2.7 m on both banks, whereas median distance of passage for large fish was 5.6 m on the north bank and 7.5 m on the south bank (Figure 11). Large fish were distributed more offshore than were small fish (Figures 10 and 11).

Length distribution of large fish varied by seasonal period (Figures 12 and 13). During the 2019 season, the average length of large fish increased as the season progressed, averaging 87.0 cm AL during 15 June–14 July and increasing to an average of 92.6 cm AL during 19–31 August (Figure 12). More variability was seen during the 2020 season, but the final period (15–22 August) also had the largest average fish size relative to the other periods (Figure 13).

CHINOOK SALMON PASSAGE ESTIMATE

Assuming all "large fish" are Chinook salmon, an estimated 4,507 (SE = 184) late-run Chinook salmon ≥75 cm AL passed the Kasilof River sonar site between 15 June and 31 August 2019. Median passage of Chinook salmon ≥75 cm AL in 2019 occurred on 28 July (Table 6, Figure 14). An estimated 3,388 (SE = 165) late-run Chinook salmon ≥75 cm AL passed the Kasilof River sonar site between 15 June and 22 August 2020. Median passage of Chinook salmon ≥75 cm AL in 2020 occurred on 31 July (Table 7, Figure 14).

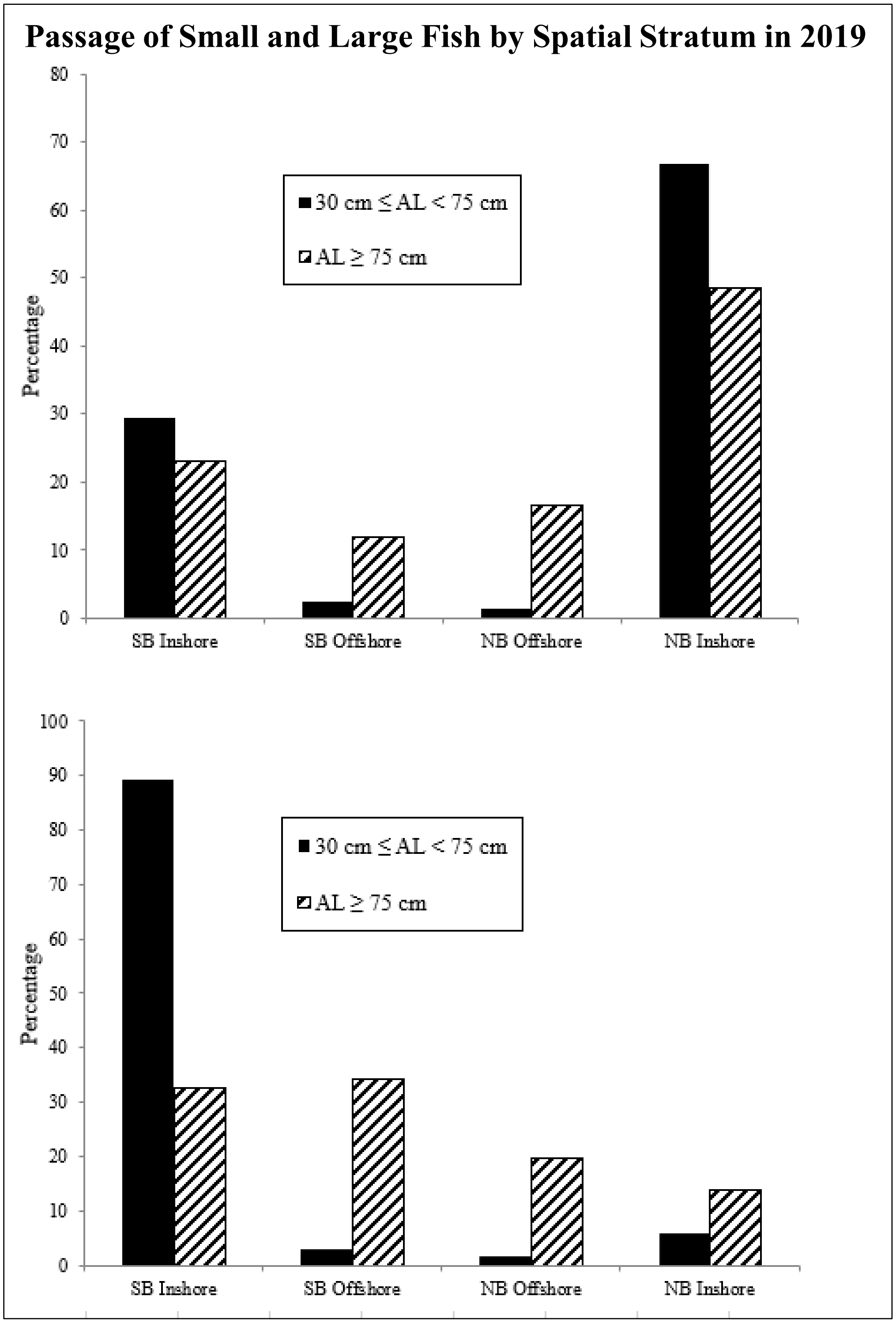

Figure 8.–Percent upstream (top) and downstream (bottom) passage of small fish (30 cm ≤ AL < 75 cm; solid) and large fish (≥75 cm AL; hatched) by spatial stratum, Kasilof River sonar, 2019.

Note: SB means south bank and NB means north bank.

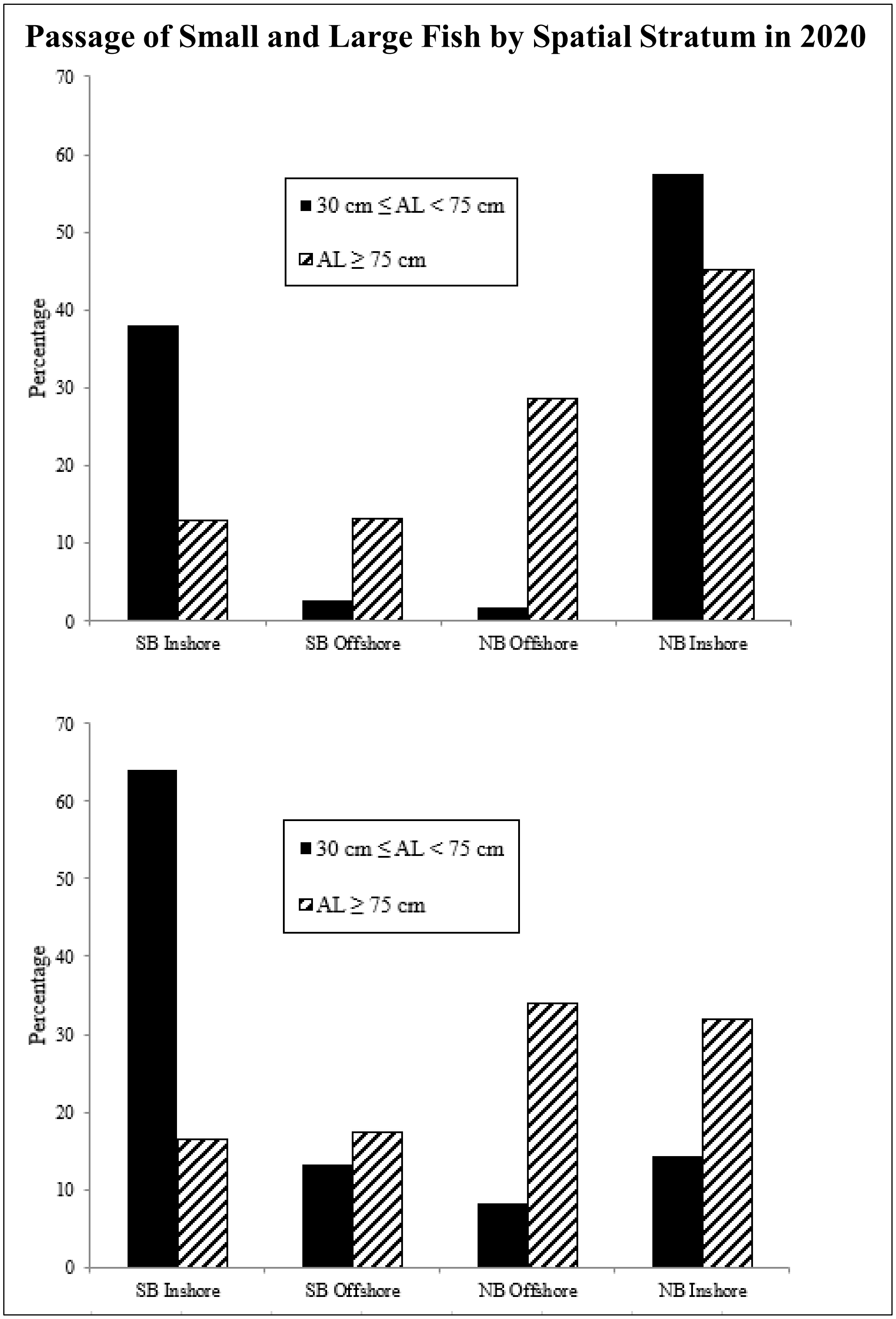

Figure 9.–Percent upstream (top) and downstream (bottom) passage of small fish (30 cm ≤ AL < 75 cm; solid) and large fish (≥75 cm AL; hatched) by spatial stratum, Kasilof River sonar, 2020.

Note: SB means south bank and NB means north bank.

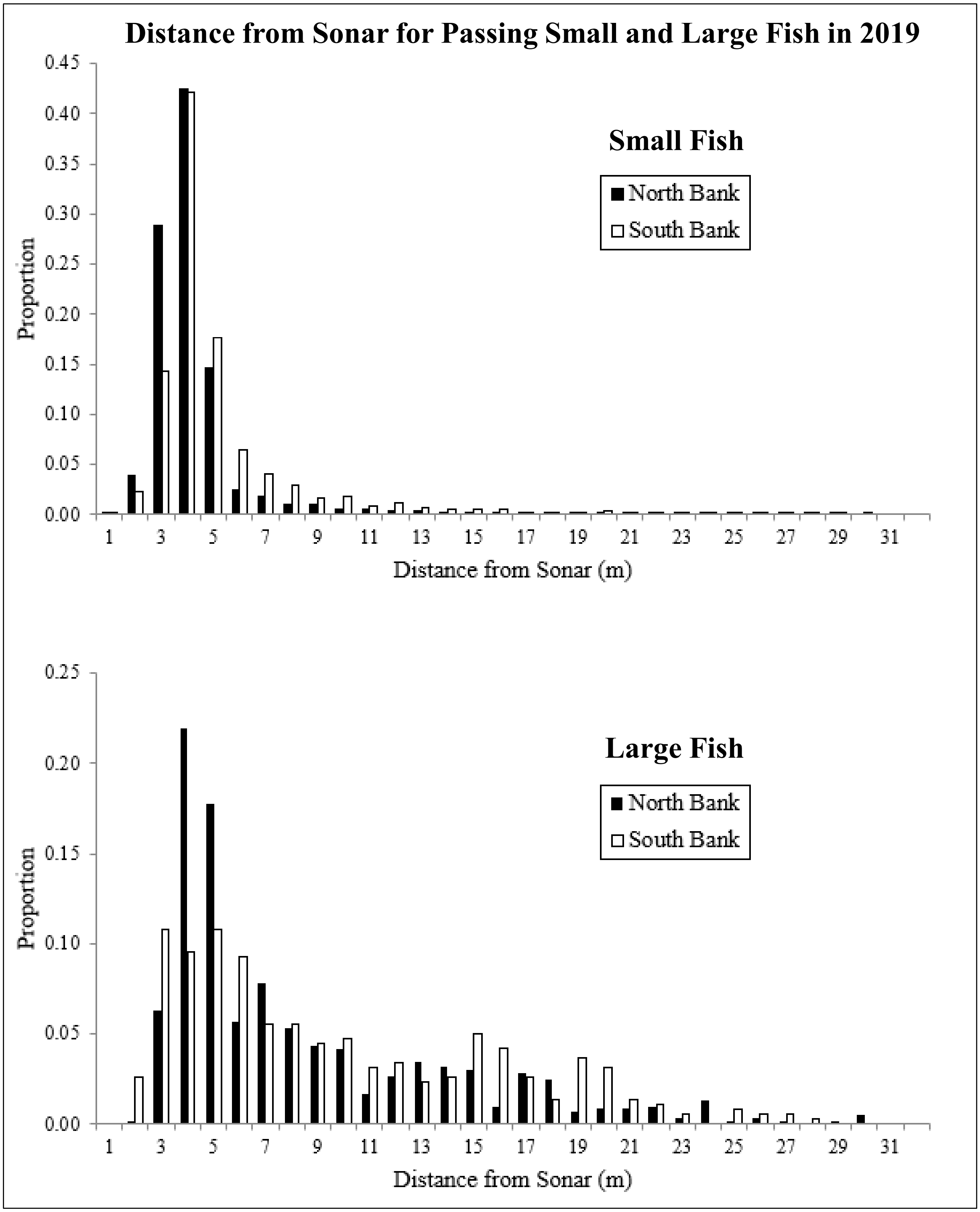

Figure 10.–Proportion of passage of small fish (30 cm ≤ AL < 75 cm; top) and large fish (≥75 cm; bottom) relative to distance from sonar for each bank (north and south), Kasilof River sonar, 2019.

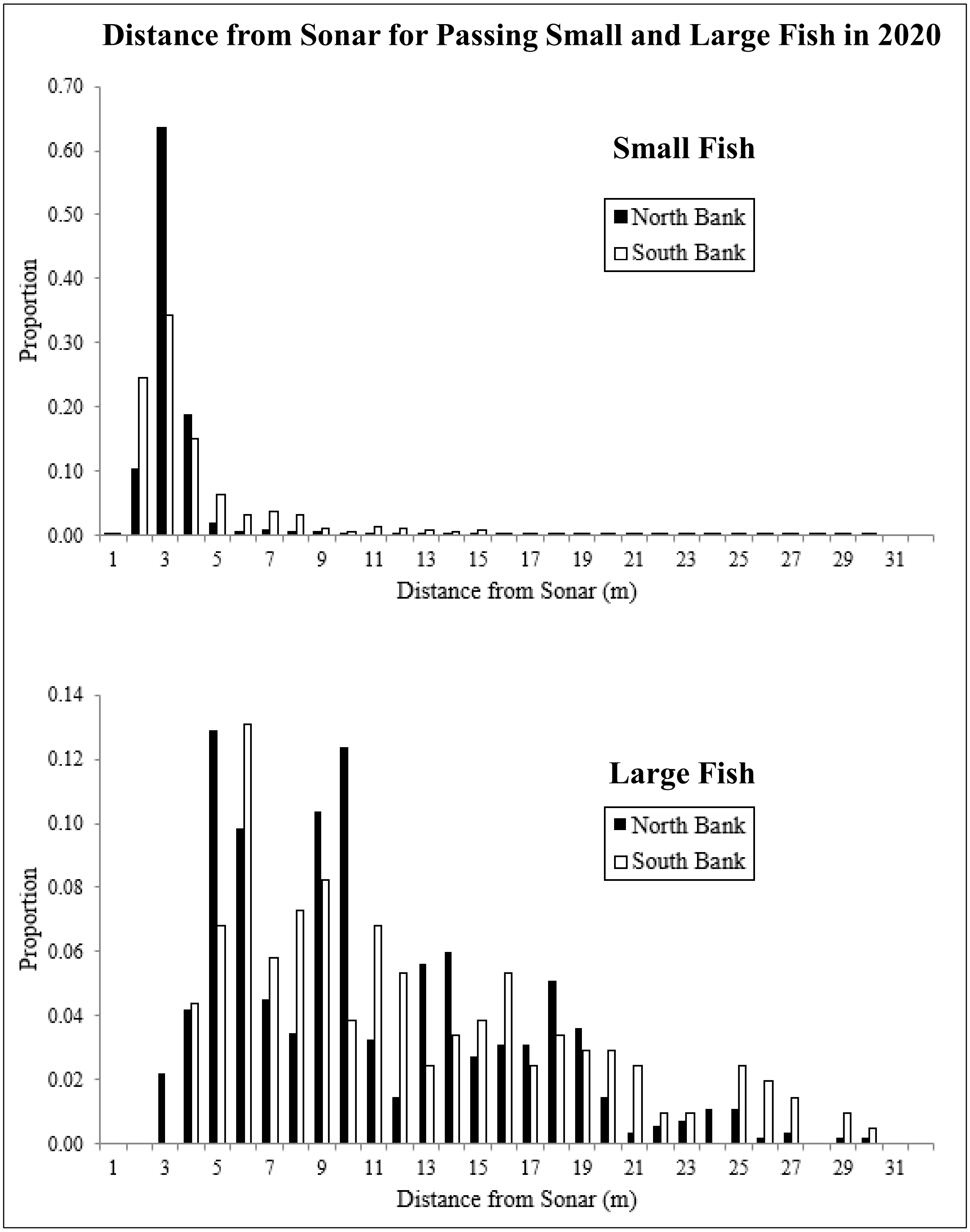

Figure 11.–Proportion of passage of small fish (30 cm ≤ AL < 75 cm; top) and large fish (≥75 cm; bottom) relative to distance from sonar for each bank (north and south), Kasilof River sonar, 2020.

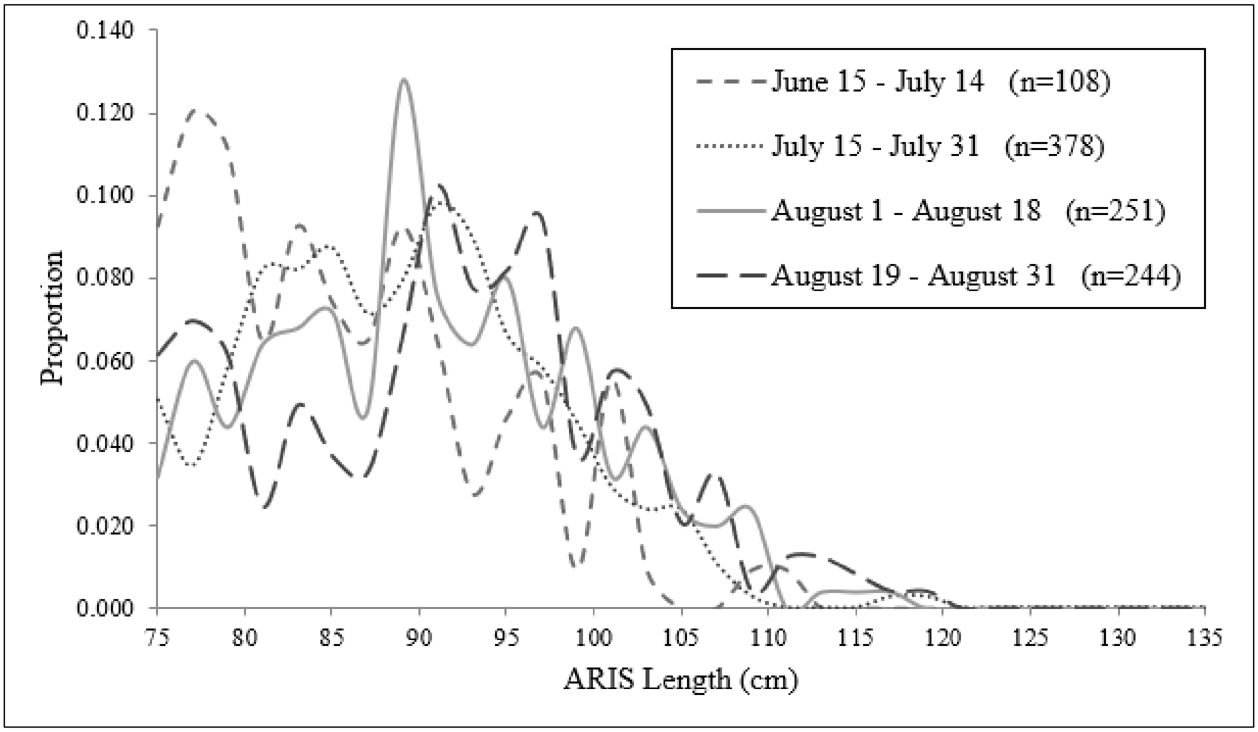

Figure 12.–Length frequency distribution of large fish (≥75 cm AL) by time period, Kasilof River sonar, 2019.

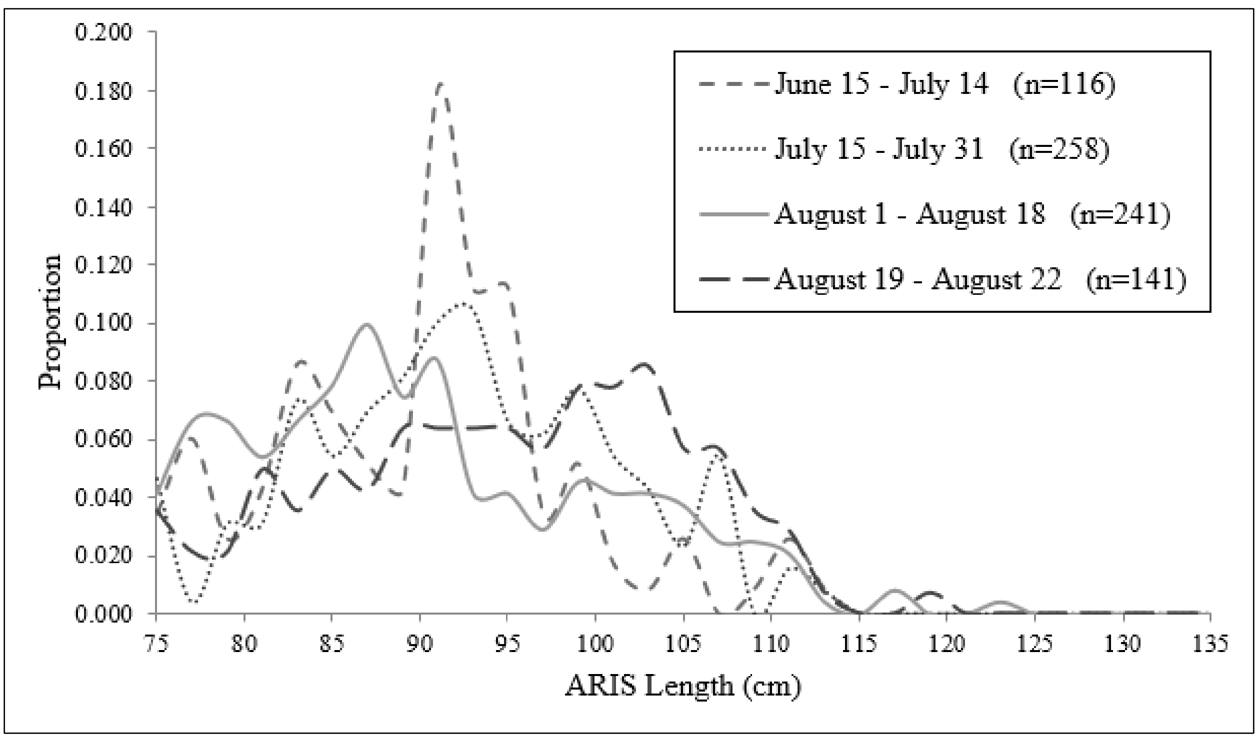

Figure 13.–Length frequency distribution of large fish (≥75 cm AL) by time period, Kasilof River sonar, 2020.

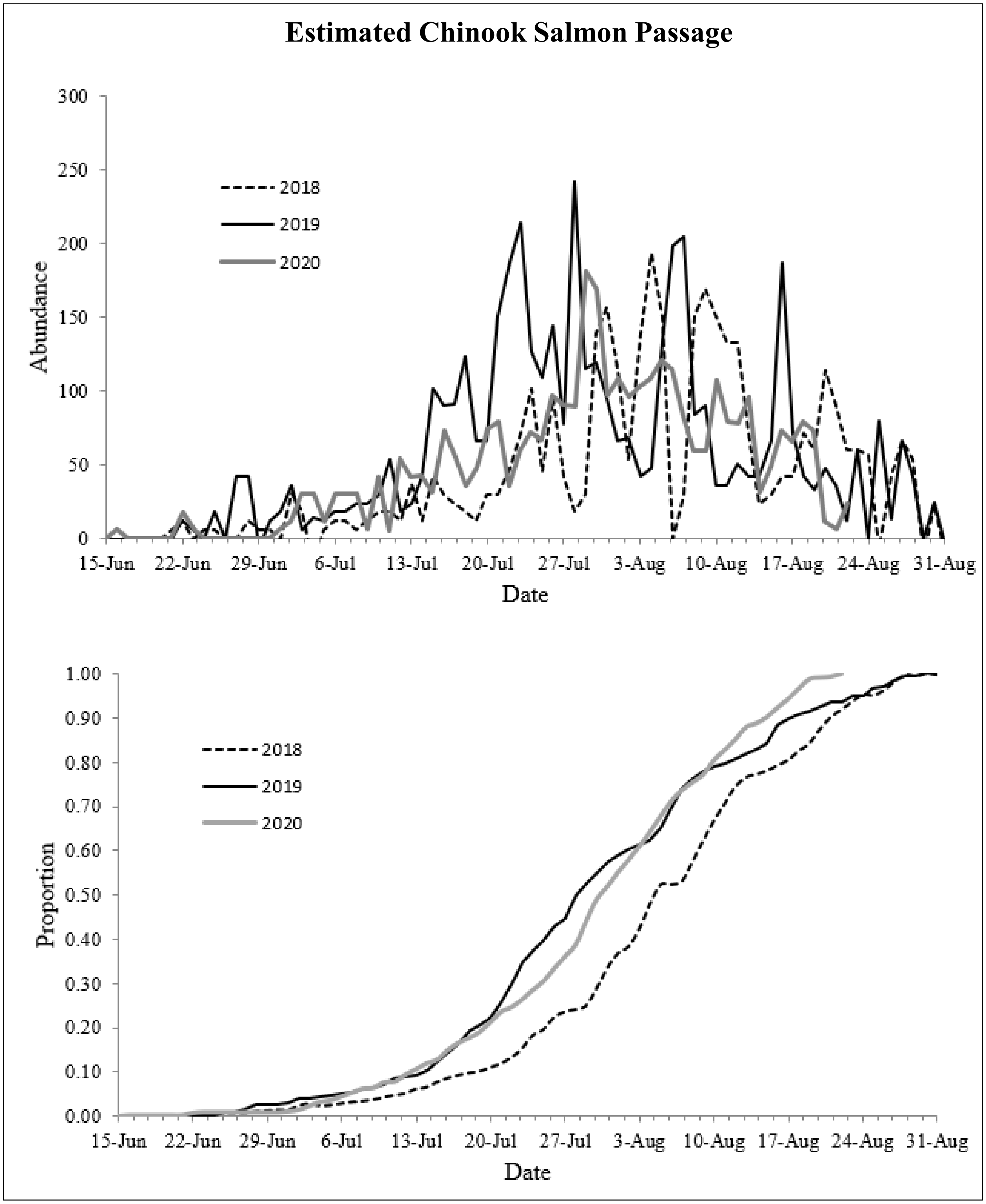

Figure 14.–Daily abundance (top) and cumulative daily proportion of end-of-season abundance (bottom) estimated for Kasilof River late-run Chinook salmon greater than or equal to 75 cm ARIS length (AL), 2018–2020.

Note: The 2018 estimates taken from Miller et al. (2020).

Table 6.–Net upstream daily passage of late-run Chinook salmon ≥75 cm ARIS length (AL), Kasilof River, 2019.

	Fish ≥75 cm AL			Fish ≥75 cm AL	
Date	Passage	SE	Date	Passage	SE
15 Jun	0	0	24 Jul	127	24
16 Jun	0	0	25 Jul	109	17
17 Jun	0	0	26 Jul	145	29
18 Jun	0	0	27 Jul	78	21
19 Jun	0	0	28 Jul	242	37
20 Jun	0	0	29 Jul	115	22
21 Jun	0	0	30 Jul	120	26
22 Jun	12	11	31 Jul	96	23
23 Jun	6	6	1 Aug	66	24
24 Jun	0	6	2 Aug	68	20
25 Jun	18	10	3 Aug	42	13
26 Jun	0	7	4 Aug	48	15
27 Jun	42	15	5 Aug	133	27
28 Jun	42	18	6 Aug	199	30
29 Jun	-6	17	7 Aug	205	39
30 Jun	12	13	8 Aug	84	41
1 Jul	18	13	9 Aug	90	27
2 Jul	36	17	10 Aug	36	16
3 Jul	6	6	11 Aug	36	21
4 Jul	14	9	12 Aug	51	19
5 Jul	12	8	13 Aug	42	21
6 Jul	18	10	14 Aug	42	16
7 Jul	18	13	15 Aug	66	27
8 Jul	24	10	16 Aug	187	29
9 Jul	24	10	17 Aug	72	21
10 Jul	30	19	18 Aug	42	13
11 Jul	54	17	19 Aug	33	27
12 Jul	18	12	20 Aug	48	15
13 Jul	24	14	21 Aug	36	26
14 Jul	42	15	22 Aug	12	22
15 Jul	102	21	23 Aug	60	31
16 Jul	90	31	24 Aug	0	24
17 Jul	91	20	25 Aug	80	21
18 Jul	124	19	26 Aug	13	28
19 Jul	66	18	27 Aug	66	24
20 Jul	66	27	28 Aug	42	24
21 Jul	151	33	29 Aug	0	14
22 Jul	187	33	30 Aug	25	25
23 Jul	214	42	31 Aug	-4	14
			Total	4,507	184

Table 7.–Net upstream daily passage of late-run Chinook salmon ≥75 cm ARIS length (AL), Kasilof River, 2020.

	Fish ≥75 cm AL			Fish ≥75 cm AL	
Date	Passage	SE	Date	Passage	SE
15 Jun	0	0	20 Jul	74	31
16 Jun	6	6	21 Jul	79	23
17 Jun	0	0	22 Jul	36	14
18 Jun	0	0	23 Jul	60	18
19 Jun	0	0	24 Jul	72	20
20 Jun	0	0	25 Jul	67	20
21 Jun	0	0	26 Jul	97	22
22 Jun	18	10	27 Jul	91	17
23 Jun	6	6	28 Jul	90	39
24 Jun	0	0	29 Jul	181	29
25 Jun	0	0	30 Jul	169	38
26 Jun	0	0	31 Jul	97	29
27 Jun	0	0	1 Aug	109	21
28 Jun	0	0	2 Aug	96	20
29 Jun	0	0	3 Aug	103	36
30 Jun	0	0	4 Aug	109	28
1 Jul	6	6	5 Aug	121	34
2 Jul	12	8	6 Aug	115	25
3 Jul	30	11	7 Aug	84	19
4 Jul	30	13	8 Aug	60	21
5 Jul	12	8	9 Aug	60	21
6 Jul	30	14	10 Aug	108	34
7 Jul	30	12	11 Aug	79	22
8 Jul	30	13	12 Aug	78	24
9 Jul	6	9	13 Aug	96	21
10 Jul	42	22	14 Aug	31	13
11 Jul	5	31	15 Aug	48	19
12 Jul	54	18	16 Aug	73	20
13 Jul	42	13	17 Aug	66	21
14 Jul	43	26	18 Aug	79	33
15 Jul	31	19	19 Aug	73	21
16 Jul	73	22	20 Aug	12	29
17 Jul	55	21	21 Aug	6	22
18 Jul	36	14	22 Aug	24	24
19 Jul	48	17	Total	3,388	165

LFO Protocol Analysis

Miller et al. (2020) used the large fish only (LFO) protocol sparingly in 2018; only 104 of 3,720 hourly samples exceeded the 100-fish threshold used that season. During the postseason all-fish measurement of the LFO samples, 23 fish greater than or equal to 75 cm were counted; however, only 21 of those were counted during LFO processing. It is likely that the 2 missed fish were LFO processing errors rather than measurement errors because they were both about 90 cm in length.

The LFO protocol was used on 359 of 3,720 inshore hourly samples during the 2019 season (50-fish threshold). During the postseason all-fish measurement of these samples, 102 fish greater than or equal to 75 cm were counted, whereas 101 were counted during LFO processing. The missed fish was approximately 78 cm in length and may have been unobserved or undermeasured.

We estimate the combined (2018 and 2019) fraction of fish counted during LFO processing to be θ = 0.976 (SE = 0.14). With respect to our total abundance estimate, a significantly larger fraction of the total fish were counted because some fish migrate in the offshore strata where the LFO protocol is not used (see Figures 8 and 9) and because θ overestimates LFO misses (see *Methods*).

DISCUSSION

Sonar was first used to estimate abundance of large Chinook salmon (≥75 cm AL) on the Kasilof River in 2018. The 2019 abundance estimate of 4,507 large Chinook salmon was larger than the 2018 estimate (3,458), whereas the 2020 estimate (3,388) was similar to the 2018 estimate. Chinook salmon abundance estimates from all three years were lower than estimates derived from the 2005–2008 mark–recapture study (Reimer and Fleischman 2012). The mode of abundance estimated using mark–recapture techniques from 2005 to 2008 ranges from 6,904 to 10,648 fish when the estimates are reduced[8] to account for just the escapement of fish greater than or equal to 75 cm METF.

Chinook salmon run timing in 2019 and 2020 was earlier than that observed in 2018. The midpoint of the 2019 run (28 July) was 8 days earlier than the midpoint of the 2018 run (5 August), and the midpoint of the 2020 run (31 July) was 4 days earlier. Run timing in 2018–2020 was consistent with (CPUE) data collected 2.5–5 miles downstream during the Reimer and Fleischman (2012) study. During those study years (2005–2008), Chinook salmon catch rates began to increase in mid- to late July and continued through most of August.

As was the case in 2018, the average METF lengths of sockeye salmon caught in a fish wheel near the sonar site in 2019 and 2020 were smaller than the average AL of small fish measured by the Kasilof River sonar crew (Figure 15). The difference between these measurements for all 3 years (3.6 cm in 2018, 3.7 cm in 2019, and 2.7 in 2020) is in the same direction but larger than expected from Kenai River tethered fish (Miller et al. 2016a). This discrepancy is likely due to some combination of coho salmon measured for AL, sampling bias by the fish wheel, or a difference in the AL to METF relationship specific to the Kasilof River drainage. In a fish wheel selectivity study conducted on the Yentna River from 2009 to 2012, Willette et al. (2016) found significant differences in fish wheel recapture probabilities across years, within years, and between length classes for each species studied (pink, sockeye, coho, and chum salmon). In an unpublished study

[8] We performed a crude adjustment for comparison only. The proportion of fish 75 cm METF or longer (amongst fish sampled after 10 July of each year) was multiplied by the posterior median of estimated abundance for the same year. Only fish sampled after 10 July are included because prior to 10 July, significant numbers Crooked Creek Chinook salmon were present (see Reimer and Fleischman 2012: Table 4).

conducted on the Yentna River in 2012, one of the authors (S. Maxwell, ADF&G, Division of Commercial Fisheries, Soldotna) found AL and FL (tip of snout to fork of tail) measurements to be nearly equivalent for a grouped sample of free-swimming sockeye, pink, coho, and chum salmon released into the sonar beam 4 m from the face of the transducer.

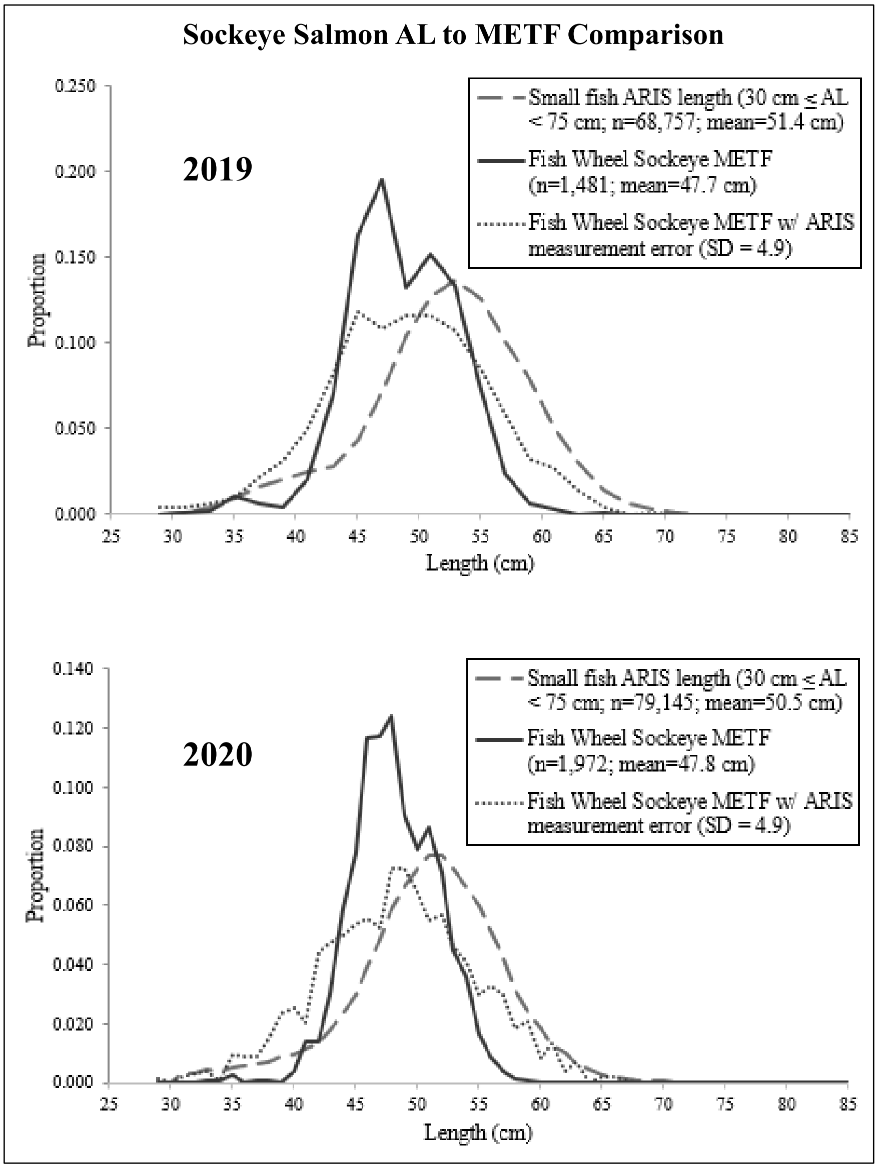

Figure 15.–Length frequency distribution of small fish (30 cm ≤ AL < 75 cm) measured using ARIS (dashed line) and all sockeye salmon captured in the fish wheels (METF; solid line; Dawn Wilburn, personal communication, ADF&G Fisheries Biologist, Soldotna, Alaska) at the Kasilof River sonar site, 2019 (top) and 2020 (bottom).

Note: Dotted line illustrates the derived length distribution after accounting for ARIS length measurement error (Normal[0, 4.9 cm]) estimated from tethered fish studies conducted on the Kenai River (*cf.* Miller et al. [2016]). “METF” means mid eye to tail fork length.

We have now evaluated bias associated with using LFO processing during 2 seasons for the Kasilof River Chinook salmon sonar. Empirical estimates of the percentage of large fish counted during the LFO procedure were higher in 2019 (~99%) compared to 2018 (~91%). It is important to note that considerably more fish were measured in 2019, thus our estimate of the overall percentage of large fish counted during the LFO procedure (0.976) is strongly influenced by the empirical data from 2019. Our analysis assumes this percentage is constant between years, although it is likely that training procedures improved between seasons, reducing the bias in 2019.

Measurement errors that occur when a fish is measured smaller than its actual size and it results in that fish being omitted from the LFO count are conflated with fish missed during LFO processing. There are also measurement errors when a fish is measured larger than its actual size and it results in that fish being counted erroneously during the LFO procedure. For this analysis, we removed those fish because fish size was verified by the project biologist postseason and we were concerned with the LFO procedure causing a negative bias in the final count. However, a separate analysis that allowed for errors in either direction found an insignificant difference between the LFO and postseason counts in both years.

During the 2018 and 2019 seasons, the LFO procedure was used sparingly on a small fraction of the total number of large Chinook salmon measured (23 of 821 in 2018 and 103 of 981 in 2019) because the procedure was only applied when the number of fish in a 10-minute counting file exceeded a certain threshold (100 fish in 2018 and 50 fish in 2019). If the LFO procedure, which measures the first 5 fish and only large fish thereafter, had been used exclusively, more fish would have been subject to LFO processing (316 in 2018 and 490 in 2019), with the remainder measured irrespective of their size because they were recorded on files that contained less than 5 total fish. Because only small numbers of fish are missed during LFO processing and upwards of half of the migrating Chinook salmon pass in strata not subject to LFO processing, we conclude that exclusive use of LFO processing would result in minimal bias particularly if training to minimize LFO errors is emphasized each season.

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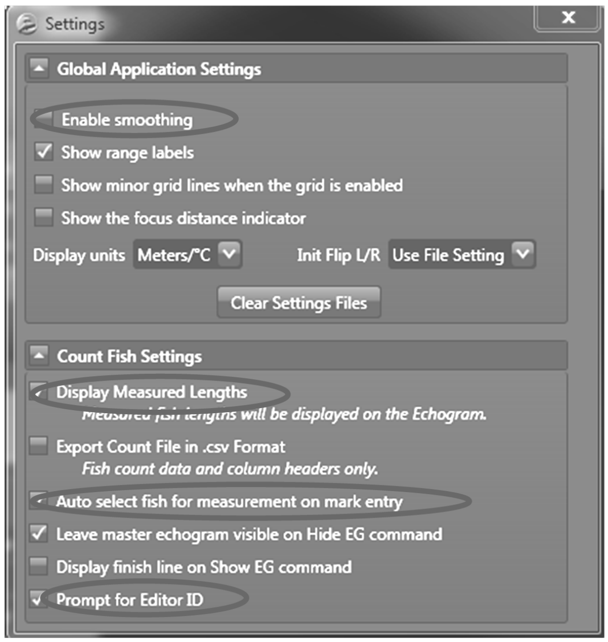
APPENDIX A: INSTRUCTIONS AND SETTINGS USED FOR MANUAL FISH LENGTH MEASUREMENTS FROM ARIS IMAGES USING ARISFISH SOFTWARE VERSION 2.6

Appendix A1.–Instructions and settings for manual length measurements from ARIS images using ARISFish version 2.6.

Set Global Settings after a NEW installation of ARISFish:

1. Open ARISFish global settings and ensure you have the following settings to measure fish:



2. Enable smoothing is ***off***.
3. Display Measured Lengths is ***on***.
4. Auto select fish for measurement on mark entry is ***on***.
5. Prompt for Editor ID is ***on***.

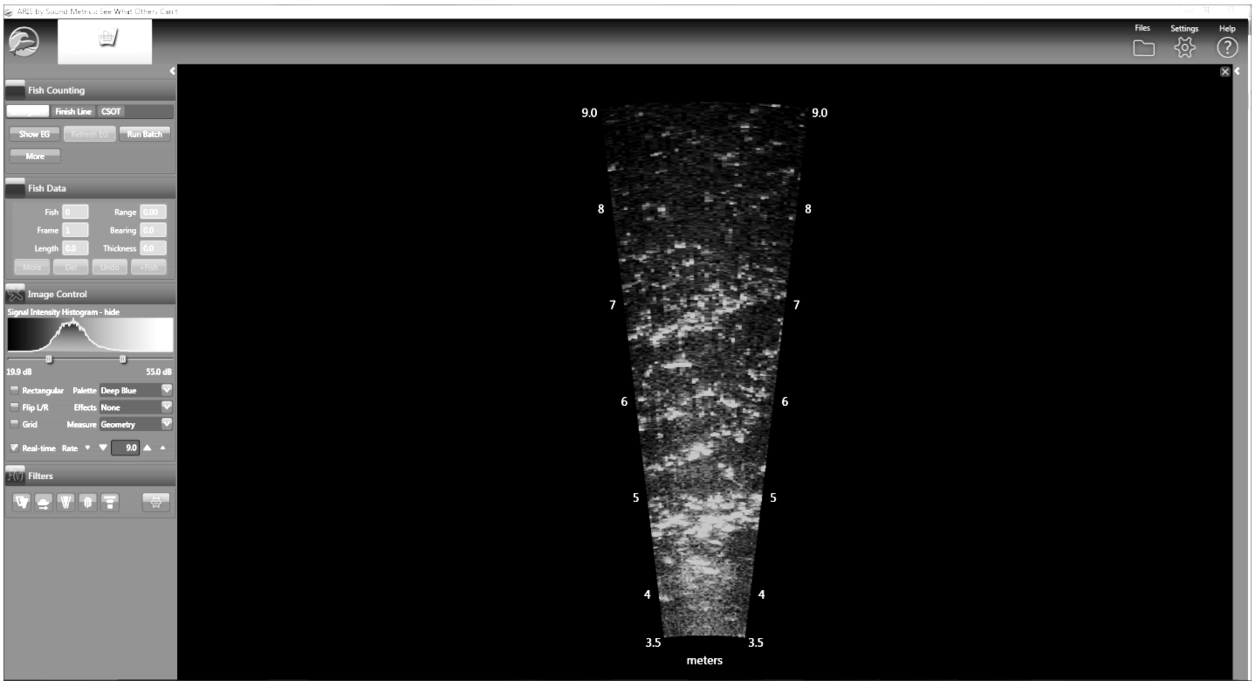
Set processing parameters for a new set of files for a new day or stratum:

1. Select **<Files> <Open Recently Viewed>**

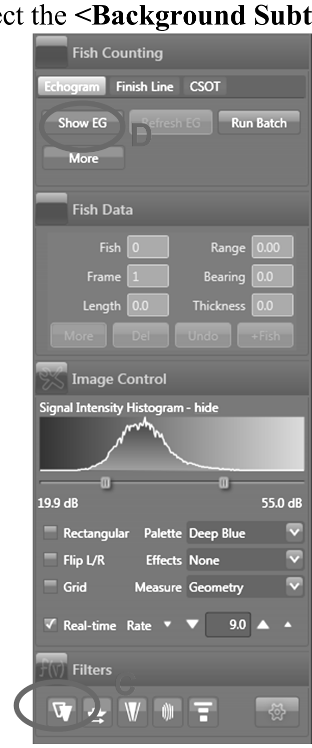
2. Navigate to the appropriate directory and open a file (or simply double click on the file of interest)

-continued-

At this point, the ARISFish display should look similar to the image below:



3. Select the **<Background Subtraction>** icon and wait about 30 seconds background to subtract.



4. Then select **<Show EG>** to display the Echogram.
5. You will be prompted to enter your Editor ID. Press OK.

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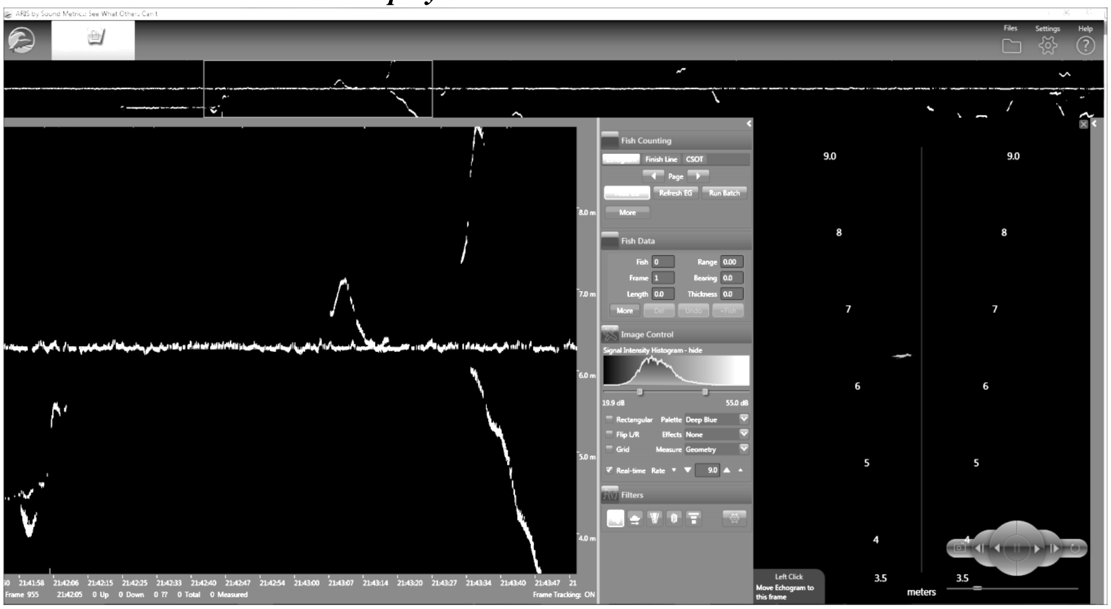
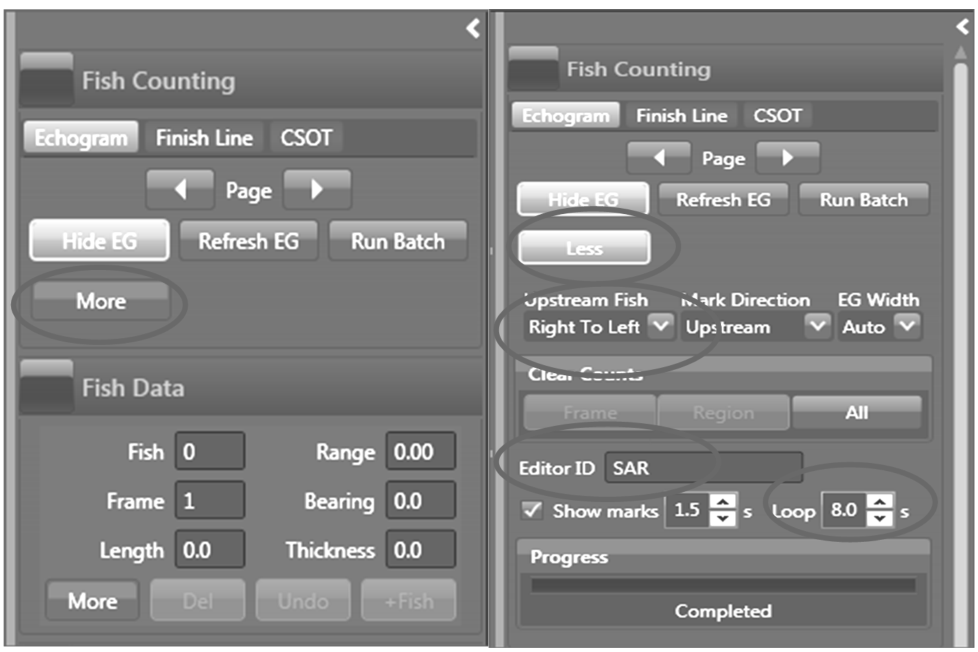
Your display should now look like the one below



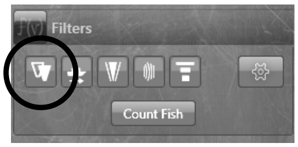
6. Select **<More>** from the Fish Counting window to get the extended window where you can
   a. enter your **Editor ID** initials
   b. set the **Upstream Fish** direction
   c. ensure that **Loop** length is set to at least 8 seconds



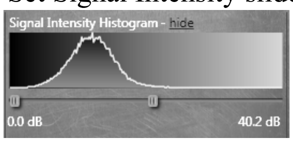
   d. then select **Less** to unexpand Fish Counting window (you'll be able to access other controls like BS easier if you do this).

-continued-

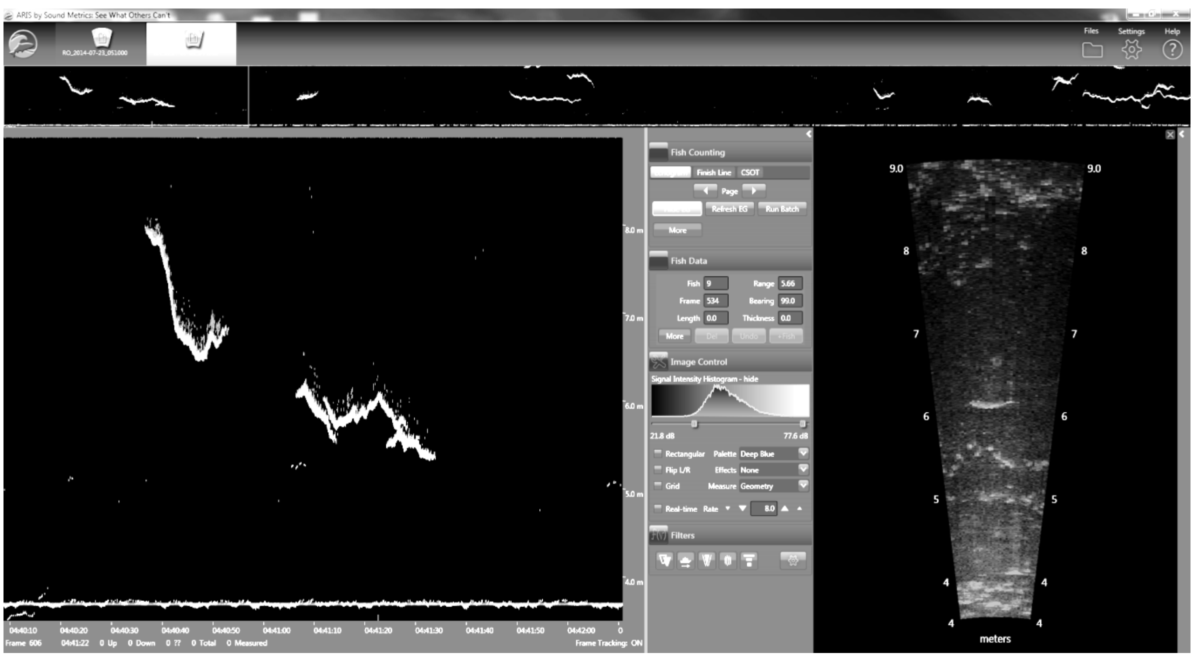
7. Select **<Background Subtraction>** icon on Filters Menu (Toggle)—this will now turn background subtraction off on the video image. **Failing to turn background subtraction off prior to measuring fish image length may result in an underestimate of actual fish length.**[1]



8. Set Signal Intensity sliders to optimize video image for measuring fish.



9. Your overall display should look similar to the following:



10. Now you are ready to start measuring (or marking) individual fish.
11. Once finished measure/marking all fish in the file, turn **<Background Subtraction>** on prior to advancing to the next file.

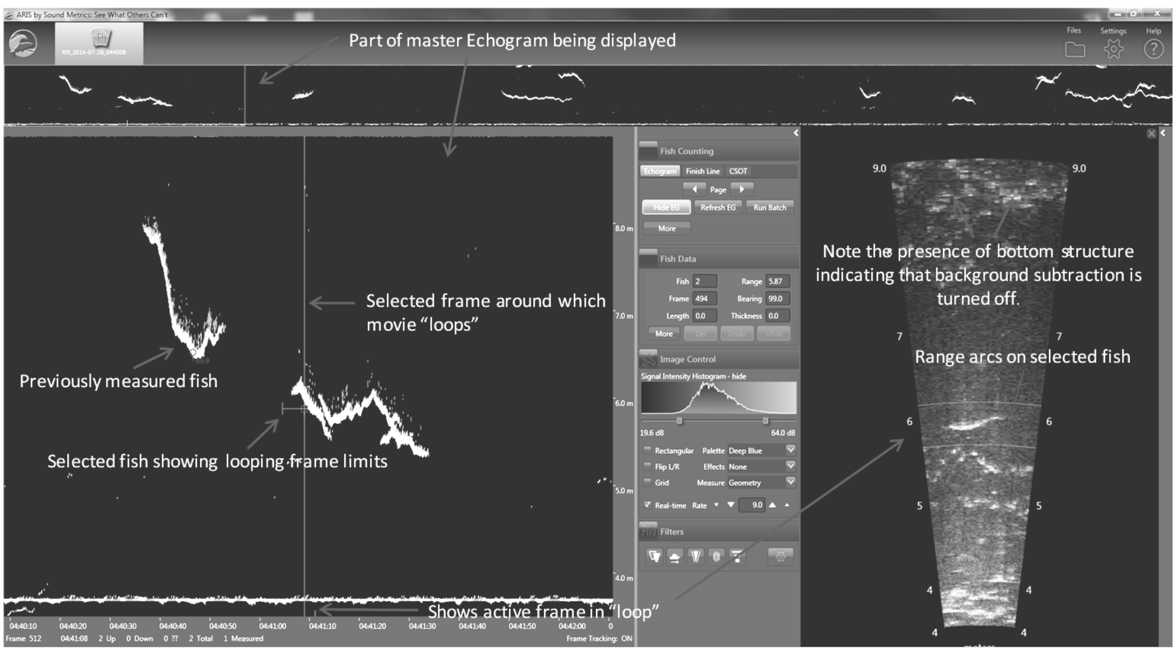
-continued-

[1] Now that we use ARIS instead of DIDSON, we mostly no longer use the background selection option while measuring fish image length. The ARIS background selection algorithm is more aggressive than the DIDSON selection and unless one is very careful in selecting a frame, it is easy to underestimate fish length. Toggling between background selection mode and the raw image can sometimes be helpful in determining the end of the tail or snout. If we do use background selection, we generally take background selection off before finalizing the measurement. A well selected frame will give the same length measurement with or without background selection.

12. Select **<Alt><right arrow>** to advance to the next file.
13. Once the new file opens, turn **<Background Subtraction>** off before beginning to measure fish (all other parameter settings and display configuration settings should be preserved from the previous file).
14. When you switch banks, you will need to reset the direction of travel parameter in step 5.
15. Now you are ready to start measuring/marking fish in the new file.

Instructions for manual fish length measurements using SMC ARISFish software version 2.6:

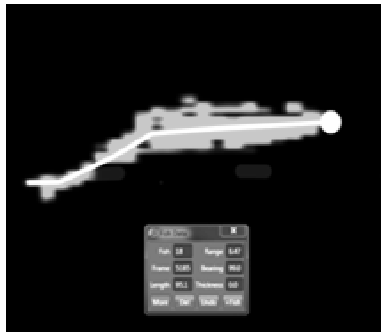
1. Ensure **<Background Subtraction>** is toggled ***off*** as described in step 6 above.
2. **<Left Click>** on the Echogram fish to be measured (Puts red marker on fish and automatically activates the movie showing the fish bounded by range arcs.
3. Press **<space bar>** to start or stop the video playback.



4. Use **<right arrow>** and **<left arrow>** to step through movie one frame at a time to find a frame that displays the entire fish length well.
   a. Measurements should be taken from frames where contrast between the fish image and background are high and where the fish displays its full length.
   b. In general, the best images are obtained when the fish is sinusoidal in shape (rather than straight and/or perfectly perpendicular to the sonar beam.
   c. Watching the behavior of the head and especially the tail over several frames, and taking several measurement, is often helpful in distinguishing the best frame.
5. **<Right Click Drag>** on movie image to zoom in for measurement.
6. **<Left Click Drag>** if necessary to center movie window prior to measuring.

-continued-

7. Measure fish image:
    a. Fish traveling snout-first upstream or downstream - **<left click>** on the fish snout and continue to **<left click>** along the midline of the fish to create a "segmented measurement." The segments should follow the midline of the body of the fish, ending with the tail.
    b. Fish backing downstream through the beam tail-first - **<left click>** on the fish tail and continue to **<left click>** along the midline of the fish to create a "segmented measurement." The segments should follow the midline of the body of the fish, ending with the snout.



    c. Toggling between BS mode and the raw image can sometimes be helpful in determining the actual end of the tail or snout.
8. Select **<f>** key to add measurement to the .txt file (fish it!)—you will see measurement in red (**<Left Click>** on echogram inside mark, if you want to delete measurement and start over).
9. Select **<v>** key to unzoom movie window (not necessary if you have another fish nearby you want to measure).
10. Next fish…repeat steps 1–8, or
11. Occasionally press <E> to save your work on each sequence when complete (or before you divert to another task).
12. **<Left Click>** on Master Echogram to advance to new echogram section, or
13. **<Alt><Right Arrow>** to advance to next file.

To mark (count) fish in SMC ARISFish software version 2.6:

1. <Left Click> on the fish trace in the echogram if upstream.
2. <Ctrl> <Left Click> on the fish trace in the echogram if downstream.

Hot keys used in measuring and counting fish in SMC ARISFish software:

<e> to "save" all echogram measurements to file
<f> to "fish it" (to accept the measurement and display it on the echogram)
<u> to "undo" the last segment
<d> to "delete" all segments
<space bar> to pause in movie mode
<right arrow> forward direction when you play movie or advances frame one at a time if the movie is paused
<left arrow> opposite of above
<Left Click Drag> to show movie over the selected time
<Right Click Drag> zooms the selected area in the image when an echogram fish is selected

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Instructions for including or excluding fish to be counted or measured:

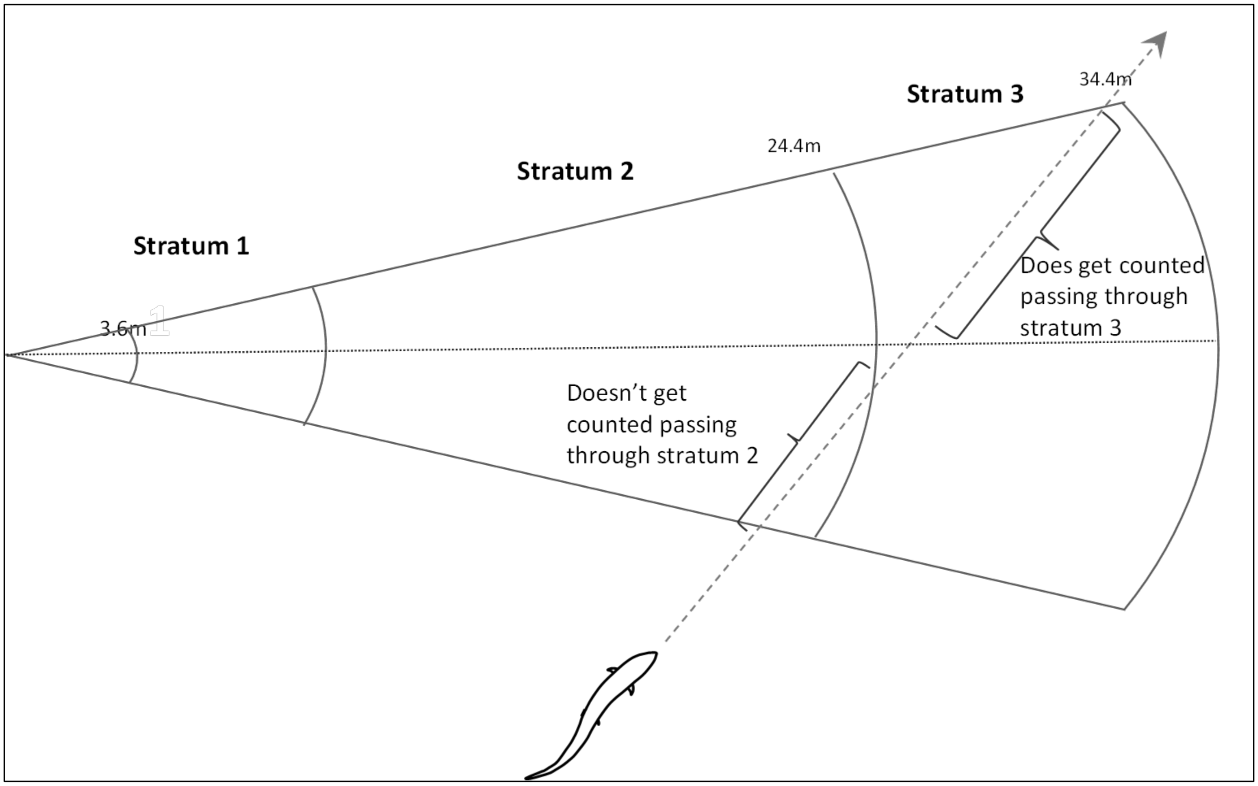
To optimize the aim of sonar beams relative to the bottom of the river, the insonified zone is often divided into individual range strata that are sampled separately. To avoid overcounting fish as they cross stratum boundaries, we apply the "centerline rule" where a fish is not counted unless it crosses the centerline of the sonar beam. Appendix A2 demonstrates the potential for overcounting without applying this criterion. Additional examples are given in Appendix A3. Note that although the centerline examples illustrated in Appendices A2 and A3 make it appear that all strata are sampled simultaneously within an hour, this is not the case. Each stratum for a given bank was sampled at different times within the hour.

Summary of fish measurement rules:

1. For a fish to be considered valid for measurement, it must cross the centerline.
   a. If a fish enters or exits the beam on the near- or far-range boundary (beginning or end range), the snout of the fish must cross the centerline before it can be considered a valid fish to measure.
   b. If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.
2. Exclude fish that hold throughout the length of the sample.
3. Exclude fish that are holding at either the beginning or the end of the sample.
   a. Fish that are actively migrating (not holding) as the sample begins or ends should be considered valid targets for measurement as long as they cross the centerline.
4. Exclude fish that enter the beam from upstream, then exit the beam upstream (do not measure even if they cross the centerline).
5. Exclude fish that enter the beam from downstream and then exit the beam downstream (do not measure even if they cross the centerline).
6. Exclude fish that enter the beam from either upstream or downstream and then disappear from the image (unless there is evidence to suggest direction of travel).
7. Use the video image to identify actively migrating fish when several holding fish are present. If you have several fish holding throughout the sample, use the video mode or run your cursor across the echogram while watching the ARIS image to observe fish that are actively transiting the image. Measure fish that are actively transiting the image and that meet all criteria listed above.
8. When subjectively determining fish length under protocol #2 measure all questionably sized fish and omit fish that measure less than 75cm AL after verifying their length.

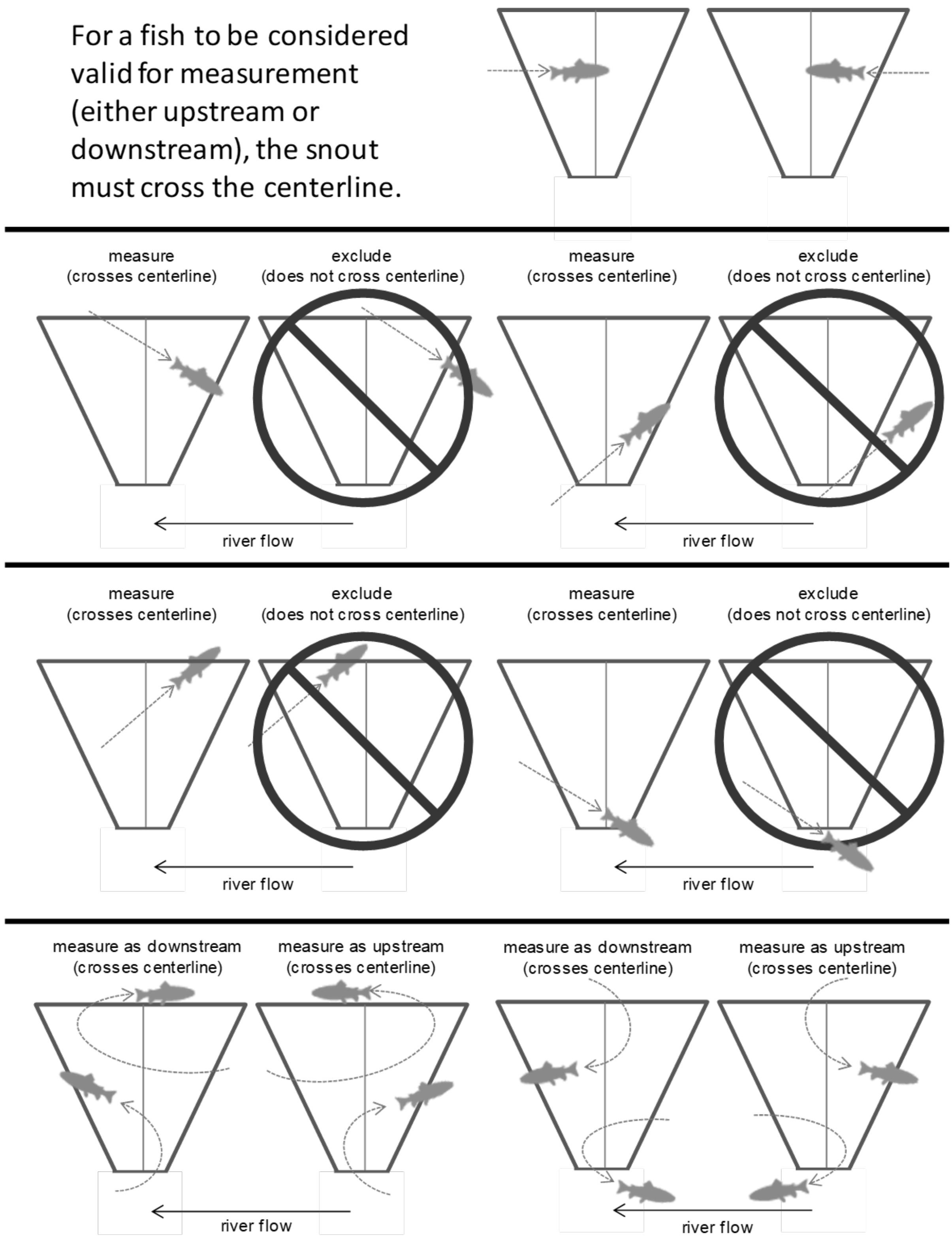
Consult with others if you come across a questionable fish image or are unclear of the rules listed above.

Appendix A2.–Illustration of how the problem of double-counting is avoided.



Note: To avoid counting this fish in both stratum 2 and stratum 3, the fish will only be counted in stratum 3 where it crosses the centerline of the beam.

Appendix A3.–Examples for applying the “centerline rule” when selecting fish for counting and measurements.



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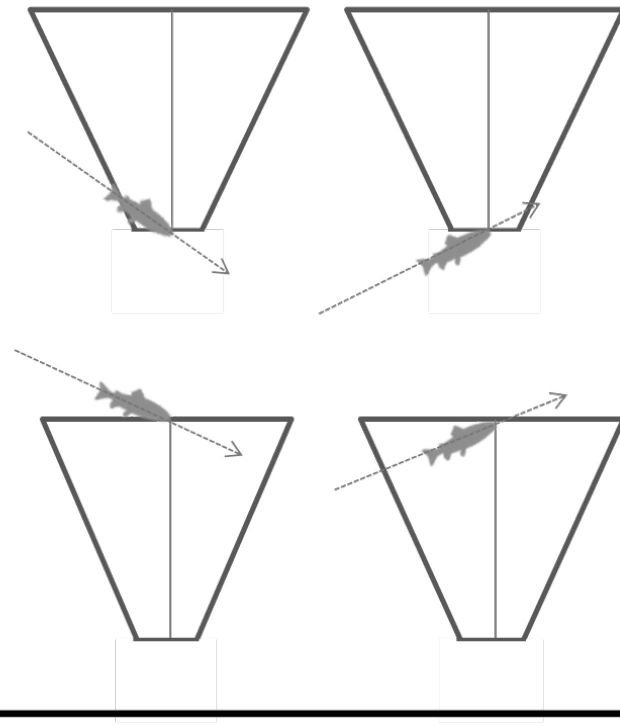
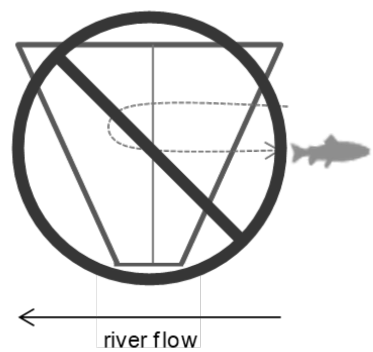
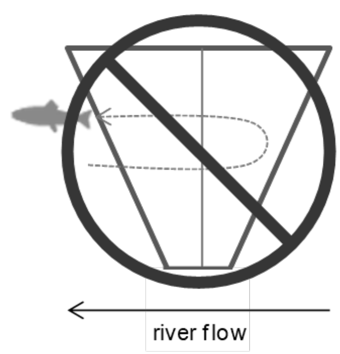
If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.



Exclude fish that enter the beam from upstream, then exit the beam upstream (do not measure even if they cross the centerline).



Exclude fish that enter the beam from downstream, then exit the beam downstream (do not measure even if they cross the centerline).



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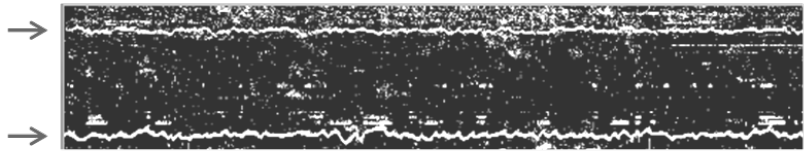
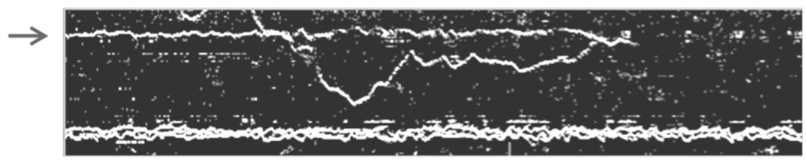
Exclude fish that hold throughout the length of the sample.

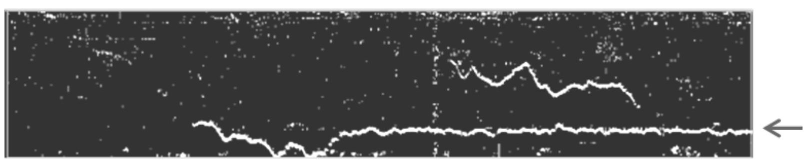


Two fish hold throughout the entire file.
Exclude both fish.

Exclude fish that hold at either the beginning or end of the sample.



Fish holding as sample begins, then exits the beam about ¾ of the way through the sample. Exclude this fish.



Fish enters the beam mid sample, then holds through the end of the sample. Exclude this fish

Fish that are actively migrating (not holding) as the sample begins or ends should be considered valid targets for measurement as long as they cross the centerline.

Fish is actively migrating through the beam as the sample starts. It crosses the center line and exits upstream so should be measured.

Consult with others if you come across a questionable fish image or are unclear of the rules listed above.

APPENDIX B: DIRECTION OF TRAVEL OF LARGE FISH DETECTED BY ARIS, KASILOF RIVER, 2019–2020

Appendix B1.–Daily count and proportion of large fish (≥75 cm ARIS length [AL]) moving upstream and downstream, Kasilof River, 2019.

	Downstream		Upstream		Total number
Date	Number	Percent (%)	Number	Percent (%)	sampled
15 Jun	0	0	0	0	0
16 Jun	0	0	0	0	0
17 Jun	0	0	0	0	0
18 Jun	0	0	0	0	0
19 Jun	0	0	0	0	0
20 Jun	0	0	0	0	0
21 Jun	0	0	0	0	0
22 Jun	0	0	2	100	2
23 Jun	0	0	1	100	1
24 Jun	1	50	1	50	2
25 Jun	0	0	3	100	3
26 Jun	1	50	1	50	2
27 Jun	1	11	8	89	9
28 Jun	2	18	9	82	11
29 Jun	4	57	3	43	7
30 Jun	2	33	4	67	6
1 Jul	0	0	3	100	3
2 Jul	1	13	7	88	8
3 Jul	0	0	1	100	1
4 Jul	0	0	2	100	2
5 Jul	0	0	2	100	2
6 Jul	0	0	3	100	3
7 Jul	1	20	4	80	5
8 Jul	0	0	4	100	4
9 Jul	0	0	4	100	4
10 Jul	1	14	6	86	7
11 Jul	0	0	8	100	8
12 Jul	2	29	5	71	7
13 Jul	0	0	4	100	4
14 Jul	0	0	7	100	7
15 Jul	0	0	17	100	17
16 Jul	0	0	15	100	15
17 Jul	0	0	15	100	15
18 Jul	0	0	21	100	21
19 Jul	1	8	12	92	13
20 Jul	2	13	13	87	15
21 Jul	5	15	29	85	34
22 Jul	0	0	31	100	31
23 Jul	0	0	36	100	36
24 Jul	1	4	22	96	23
25 Jul	0	0	18	100	18
26 Jul	0	0	24	100	24
27 Jul	1	7	13	93	14
28 Jul	1	2	41	98	42
29 Jul	1	5	20	95	21
30 Jul	0	0	20	100	20
31 Jul	2	11	17	89	19

-continued-

Appendix B1.–Page 2 of 2.

Date	Downstream Number	Downstream Percent (%)	Upstream Number	Upstream Percent (%)	Total number sampled
1 Aug	0	0	12	100	12
2 Aug	1	8	12	92	13
3 Aug	0	0	7	100	7
4 Aug	0	0	8	100	8
5 Aug	4	14	25	86	29
6 Aug	3	8	36	92	39
7 Aug	2	5	36	95	38
8 Aug	3	15	17	85	20
9 Aug	0	0	15	100	15
10 Aug	3	25	9	75	12
11 Aug	1	13	7	88	8
12 Aug	1	9	10	91	11
13 Aug	3	23	10	77	13
14 Aug	2	18	9	82	11
15 Aug	2	13	13	87	15
16 Aug	1	3	32	97	33
17 Aug	3	17	15	83	18
18 Aug	1	11	8	89	9
19 Aug	4	29	10	71	14
20 Aug	0	0	8	100	8
21 Aug	6	33	12	67	18
22 Aug	7	44	9	56	16
23 Aug	4	22	14	78	18
24 Aug	7	50	7	50	14
25 Aug	3	15	17	85	20
26 Aug	7	44	9	56	16
27 Aug	2	13	13	87	15
28 Aug	4	27	11	73	15
29 Aug	4	50	4	50	8
30 Aug	8	40	12	60	20
31 Aug	1	50	1	50	2
Total	117	12	864	88	981

Appendix B2.–Daily count and proportion of large fish (≥75 cm ARIS length [AL]) moving upstream and downstream, Kasilof River, 2020.

Date	Downstream Number	Downstream Percent (%)	Upstream Number	Upstream Percent (%)	Total number sampled
15 Jun	0	NA	0	NA	0
16 Jun	0	0	1	100	1
17 Jun	0	NA	0	NA	0
18 Jun	0	NA	0	NA	0
19 Jun	0	NA	0	NA	0
20 Jun	0	NA	0	NA	0
21 Jun	0	NA	0	NA	0
22 Jun	0	0	4	100	4
23 Jun	0	0	1	100	1
24 Jun	0	NA	0	NA	0
25 Jun	0	NA	0	NA	0
26 Jun	0	NA	0	NA	0
27 Jun	0	NA	0	NA	0
28 Jun	0	NA	0	NA	0
29 Jun	0	NA	0	NA	0
30 Jun	0	NA	0	NA	0
1 Jul	0	0	1	100	1
2 Jul	0	0	2	100	2
3 Jul	0	0	5	100	5
4 Jul	0	0	5	100	5
5 Jul	0	0	2	100	2
6 Jul	0	0	5	100	5
7 Jul	0	0	5	100	5
8 Jul	1	14	6	86	7
9 Jul	1	33	2	67	3
10 Jul	2	18	9	82	11
11 Jul	10	48	11	52	21
12 Jul	1	9	10	91	11
13 Jul	1	11	8	89	9
14 Jul	8	35	15	65	23
15 Jul	2	22	7	78	9
16 Jul	0	0	12	100	12
17 Jul	3	20	12	80	15
18 Jul	0	0	6	100	6
19 Jul	1	10	9	90	10
20 Jul	1	7	13	93	14
21 Jul	0	0	13	100	13
22 Jul	1	13	7	88	8
23 Jul	1	8	11	92	12
24 Jul	0	0	12	100	12
25 Jul	0	0	11	100	11
26 Jul	1	6	17	94	18
27 Jul	1	6	16	94	17
28 Jul	2	11	17	89	19
29 Jul	1	3	31	97	32
30 Jul	1	3	29	97	30
31 Jul	2	10	18	90	20

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Date	Downstream Number	Downstream Percent (%)	Upstream Number	Upstream Percent (%)	Total number sampled
1 Aug	1	5	19	95	20
2 Aug	1	6	17	94	18
3 Aug	2	10	19	90	21
4 Aug	2	9	21	91	23
5 Aug	1	5	21	95	22
6 Aug	2	9	21	91	23
7 Aug	0	0	14	100	14
8 Aug	2	14	12	86	14
9 Aug	0	0	10	100	10
10 Aug	1	5	19	95	20
11 Aug	1	7	14	93	15
12 Aug	2	12	15	88	17
13 Aug	0	0	15	100	15
14 Aug	2	22	7	78	9
15 Aug	1	10	9	90	10
16 Aug	2	13	14	88	16
17 Aug	2	13	13	87	15
18 Aug	6	24	19	76	25
19 Aug	6	25	18	75	24
20 Aug	8	44	10	56	18
21 Aug	8	47	9	53	17
22 Aug	6	38	10	63	16
Total	97	13	659	87	756

Note: "NA" means calculation not applicable.